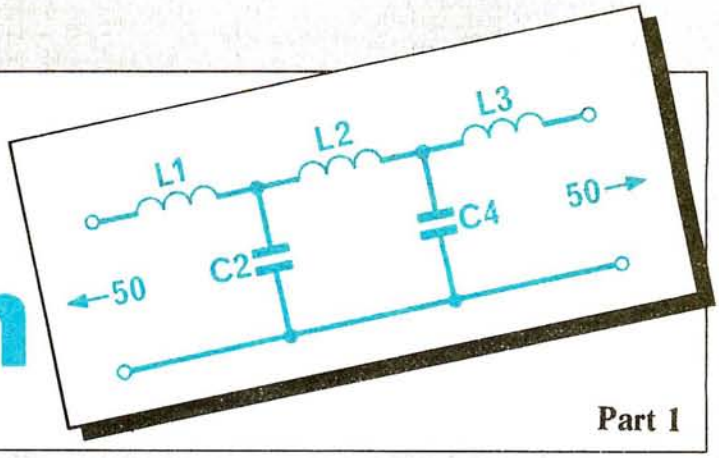
Practical LC Filter Design



by Edward Wetherhold W3NQN

Part 1

Although the passive inductor-capacitor (*LC*) filter was developed more than sixty years ago, a simple and practical design procedure still is not widely available to the radio amateur. Because this filter type has many applications in radio communications—transmitter harmonic reduction being the most common and familiar—a simplified design procedure for the amateur would be of considerable use. Modern network synthesis provides the professional filter designer with the necessary tools for designing sophisticated filters, but these procedures are unfamiliar and too inconvenient for use by the radio amateur. This article introduces a new passive *LC* filter design procedure in which one simply scans a table of precalculated designs to find a filter that is suitable for a particular application.

This new design procedure makes use of several tables of precalculated designs in which a large number of the most commonly used lowpass and highpass filters are tabulated over one decade of frequency (1–10MHz). Because of the large number of designs, the increment in cutoff frequency from one design to the next is small enough, so virtually any cutoff frequency can be selected from the table. To simplify construction, all capacitor values used in the designs are standard. By shifting the decimal points in the tabulated data, designs for other frequency decades can be obtained by inspection.

The procedures currently used by the amateur and professional filter designer involve several calculations to obtain a final design, but invariably the calculated capacitor values are not standard. Because of this, the design is more difficult to realise than it should be. In comparison, the standard-value capacitor (SVC) designs are easy to realise, because only standard-value capacitors are needed. Finding a filter using this new design technique consists of scanning the tables for a suitable design and reading out the component values. Although the designs are based on equal input and output terminations of 50 ohms, SVC designs for any equal-impedance terminations can be found using a simple scaling procedure in combination with the "scan mode" selection process. Before proceeding any further in explaining this new SVC filter design technique, a brief review of filter design and development will be presented so you can better appreciate the convenience and power of the SVC filter design tables.

History of Filter Design

The development of the first *LC* filter, independently discovered in 1915 by George Campbell in America and Karl Wagner in Germany, was based on transmission line theory [1]. A more comprehensive design procedure was published in 1923 by Otto Zobel of Bell Telephone [2]. He developed the m-derived matching sections to solve the problem of matching the filter image impedance (which varied with frequency) to a fixed resistive source and load. Zobel's image parameter filter design procedure was adequate to satisfy the filtering requirements of the electronics industry for the next thirty years. The image parameter design procedure was the only known method until about 1940 and the only practical method until the mid-1950s. The familiar terms such as "cutoff frequency", "characteristic impedance", "constant-k prototype sections", and "m-derived sections", are examples of how Zobel's invention affected the vocabulary and terminology of the communications field.

Between 1940 and 1950, a more theoretically correct design procedure was developed in which networks were synthesised to produce a desired response. Some of the people involved were Norton, Bennett, Dishall and Darlington in the US, Cauer in Germany and Cocci in Italy. This new design procedure, known as "modern filter design" or the "insertion-loss" design procedure, gradually superseded Zobel's less exact image parameter procedure. Modern filter design was found to be more versatile than Zobel's procedure and it was possible to produce networks having many different desired response characteristics with a minimum of components. Continuing application of modern filter design resulted in the development of its own unique terminology, such as "Butterworth", "Chebyshev", "Cauer" and "Bessel", to indicate a specific response type, and "passband ripple", "ripple cutoff frequency", and "minimum stopband attenuation" to describe certain characteristics of a modern filter response. In passing, it should be noted that the term "characteristic impedance" is associated solely with Zobel's image parameter design procedure, and it is not applicable when discussing modern design filters.

During the 1940s and 50s, modern filter design remained primarily in the realm of the network theorist because of the lengthy and complex mathematics required to calculate a design; however, after the development of the digital computer, it became possible to calculate and publish tables of normalised design values for the more popular filter configurations. For example, the 1958 publication of normalised Cauer-parameter (also known as elliptic function) designs by Saal and Ulrich in the *IRE Transactions on Circuit Theory* [3] gave the professional filter designer the capability to quickly and conveniently design this type of filter. In addition, Telefunken published Saal's normalised tables of Chebyshev and Cauer designs with an explanation of the design procedure in German accompanied by an English translation. This attractively bound 381-page book soon became the authoritative reference source of the professional filter designer [4]. In 1963, Philip Geffe's now classic book *Simplified Modern Filter Design* [5], also known as the "little blue book", was

the first publication to simply and clearly explain modern filter design in a manner understandable to the amateur. Since then, many other books have been published. The most recent authoritative books in English are Zverev's *Handbook of Filter Synthesis* [6] and *Filtering in the Time and Frequency Domains* by Zverev and Blinchikoff [7]. A more recent and less theoretical publication on modern filter design is *Electronic Filter Design Handbook*, by A. Williams[8]. From this brief history of passive *LC* filter design, you can appreciate the many years of effort by many different individuals that were required to reach the present state of the art.

In the following paragraphs, several of the modern filter response types and configurations will be reviewed, and those most suitable for amateur radio applications will be explored in greater detail.

Modern Filter Types

Listed in order of increasing selectivity, the most frequently used modern filter types are the Bessel, Butterworth, Chebyshev and Cauer (also known as the "elliptic"). These filters are named after the mathematicians who developed the polynomials upon which the filter responses are based. The lowpass attenuation responses of these four filters are shown in Fig. 1.1. The 3dB attenuation level has been taken as a common cutoff frequency (designated *F3* in Fig. 1.1) so the relative selectivity of the responses can be properly compared. The highpass response is the mirror image of the lowpass response.

Bessel Response—This response is characterised by a very gradual rise in attenuation that starts well within the passband with a gradually continuing attenuation rise (also called a "monotonic response") in the stopband. As you can see from the response shown in Fig. 1.1, the Bessel is not well suited for applications where an abrupt rise in attenuation is desired after the cutoff frequency. However, the Bessel provides good phase and delay characteristics to minimise waveform distortion, such as overshoot and ringing, when filtering pulse or digital waveforms. Since most amateur filtering applications are concerned with sinusoidal waveforms, such as audio or r.f. signals, the Bessel response is seldom used because of its poor amplitude response.

Butterworth—This response is similar to the Bessel in that it is monotonic in passband and stopband, and even though its attenuation rise (6dB per octave, per element) is more abrupt than the Bessel, it is not abrupt enough to be of major importance. The Butterworth response is sometimes used when a compromise is wanted between equally poor phase and amplitude performance. By coincidence, the 3-element Butterworth is identical in response and component values to the 3-element image parameter constant-k filter, but this similarity does not extend beyond three elements.

Chebyshev—This response has attenuation ripples in the passband and is monotonic in the stopband. The Chebyshev filter has the best amplitude response of the modern designs in which each branch consists of a single element. The number of ripple peaks in the passband is related to the number of branches. The 5 and 7-branch designs have 2 and 3 attenuation peaks, respectively, of the same maximum amplitude (*Ap*). This parameter directly affects the stopband attenuation slope in the first octave above the cutoff frequency. That is, the higher the value of *Ap*, the steeper the slope of stopband attenuation. After the first octave, the attenuation slope approaches 6dB per octave, per element. The cutoff frequency (*F-Ap*) for the Chebyshev and Cauer responses is that frequency where the attenuation first exceeds the *Ap* level.

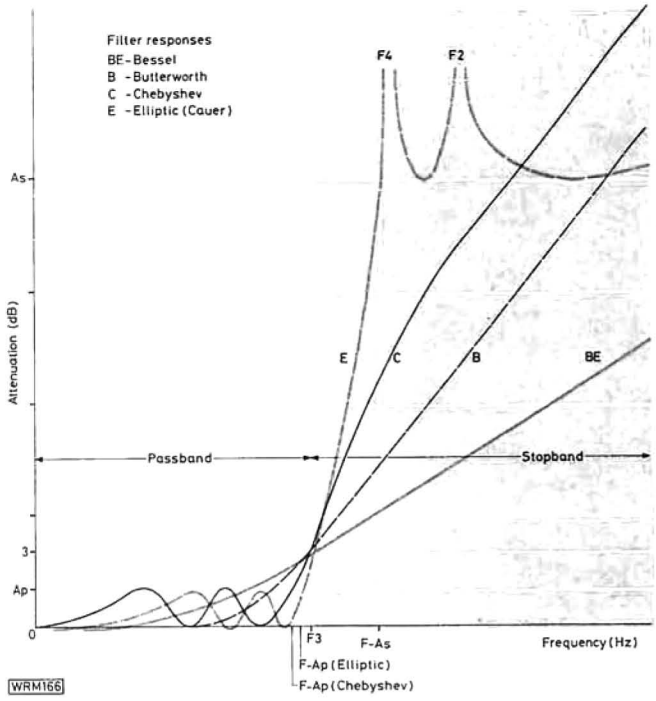


Fig. 1.1: Modern filter responses for typical 5-branch lowpass designs

The ripple amplitude in Fig. 1.1 is exaggerated for clarity. Usually, it is small enough that it is ignored because it is difficult to measure. Nevertheless, the passband amplitude is important because it is mathematically related to the v.s.w.r. and reflection coefficient of the filter. Appendix A (which appears in Part 2) gives the equations relating *Ap*, v.s.w.r. and percentage of reflection coefficient (*rc*). Because we are interested in filters with low v.s.w.r. only those Chebyshev designs having a maximum v.s.w.r. less than 1·3:1 (corresponding $Ap = 0{\cdot}074$dB and $rc = 13$ per cent) will be considered. The lowest maximum v.s.w.r. of interest is 1·020, and this corresponds to a maximum attenuation amplitude of 0·000434dB and a *rc* of 1·00 per cent. Usually, it is not necessary to know the exact v.s.w.r. at all frequencies within the passband. Instead, it is sufficient to know that the v.s.w.r. will never exceed a certain maximum value related to the passband attenuation peaks. Values of v.s.w.r. lower than 1·020 are possible, but these responses are of little interest because they are very similar to that of the Butterworth with its poor selectivity. Because the v.s.w.r. and *Ap* parameters have awkward numbers, the *rc* parameter will be used instead to define a particular design. This is the defining parameter used in most filter catalogues published today.

At this time, it is appropriate to include a brief explanation of the correct spelling of the great Russian mathematician, Pafnuti Lvovich Chebyshev (1821–1894), whose name is used to identify this filter response. Because the Russian and English alphabets are different, Russian names must be transliterated (changing letters of one alphabet into corresponding characters of another alphabet having a similar pronunciation). The correct Russian–to–English transliteration is "Chebyshev". Because many of his papers were published in French scientific journals, the French transliteration "Tchebycheff" was used. Many years later, English and American authors on network theory discovered that Chebyshev's polynomials (originally applied in calculating steam tables) were also applicable to the synthesis of elec-

DEFINITIONS

Like experts in most specialised fields, filter designers rely on a special jargon of their own. *Practical Wireless* readers unfamiliar with this subject may become confused when reading filter articles simply because they do not understand a few key words. The following is a list of some of the filter terms used in this article with a brief explanation.

Passive filter—a frequency selective network composed of passive elements (for example, inductors and capacitors) and generally classified by its filtering function (lowpass, highpass, bandpass or stopband) and response shape (for example, Butterworth, Chebyshev, etc.).

Lowpass filter—a filter that passes signal frequencies from zero frequency (d.c.) to some specified cutoff frequency, above which the signal frequencies are increasingly attenuated.

Highpass filter—a filter that passes signal frequencies above a specified cutoff frequency, below which the signal frequencies are increasingly attenuated.

Passband—the frequency range where a filter passes signal frequencies with little attenuation; that is, for a lowpass filter, from d.c. to the cutoff frequency. In the passband, the filter appears as a window between the signal source and the load, and practically all of the power is transmitted to and received by the load.

Stopband—the frequency range outside of the passband; that is, the region where signal frequencies are significantly attenuated. In the stopband, the filter appears as a mirror between the signal source and the load. Practically all of the power is reflected back to the source, and almost no power reaches the load.

Image parameter filter—a filter design based on image parameters that are related to transmission line theory. The image parameter design procedure has been largely replaced by the more convenient and efficient modern design procedure.

Constant-k prototype section—an image parameter filter section in which the series and shunt arms are inverse impedances, and the product of these impedances is independent of frequency: that is, $Z1_k) \times (Z2_k) = L1_k/C2_k = (R_k)^2$. R_k is a constant and is known as the "characteristic impedance" of the prototype section. This section is the "prototype" upon which the design of other image-parameter filter sections are based.

m-derived sections—a special image-parameter filter section invented by Otto Zobel having unusual impedance characteristics which allow a half section to be used to match the image impedance of the constant-k section to a fixed resistive termination. A full m-derived section can be inserted between two constant-k sections to produce increased stopband attenuation.

Cutoff frequency—the frequency that separates the filter passband from the stopband. For the image parameter and some modern designs, the cutoff frequency occurs at the 3dB attenuation level. For modern filter designs having passband attenuation ripple, the cutoff frequency is commonly taken at the frequency where the filter passband attenuation first exceeds the maximum ripple attenuation (*Ap*) level. The modern filter cutoff frequency is also called the "ripple cutoff frequency", and is designated "*F-Ap*".

Passband ripple—a passband attenuation characteristic of some modern filter types in which the passband attenuation ripples between zero and a maximum level. The maximum level of passband ripple amplitude is designated "*Ap*".

Modern filter—a filter designed by the application of network synthesis to produce a circuit having a desired performance. The procedure used to calculate design tables of modern filters is highly mathematical and is practical only with the aid of a digital computer. Fortunately, many computer-calculated normalised design tables of various filter types have been published, and this makes it practical for the experienced radio amateur to conveniently design modern filters.

tric wave filters, and incorrectly assumed the French transliteration could be copied directly into English. In 1955, the confusion concerning the English spelling of Chebyshev was resolved when a response to this question was received from a spokesman from the Russian Embassy and published in the correspondence section of the *IRE Transactions*. This same spelling, "Chebyshev", is used by the Russian-born and educated A. Zverev in his English publications.

Cauer—The most selective and versatile of the modern responses is the Cauer, named after the German network theorist who developed the mathematics associated with this response. Most English and American writers prefer to use the name "elliptic" to describe this response, as this is the mathematical function on which the response is based; however, since the three previous responses were named after those men credited with developing the associated mathematics, it seems consistent and appropriate to name the fourth response in the same manner.

The Cauer filter is the modern equivalent (in a more elegant form) of Zobel's constant-k prototype with m-derived intermediate and end-matching sections. The Cauer response is characterised by attenuation ripple in both the passband and stopband; however, as can be seen from Fig. 1.1, the shapes of the ripple waveforms are distinctly different. In addition to being able to select any maximum level of passband ripple, it is also possible to select any level of minimum stopband attenuation. This is an important characteristic because usually the filter stopband will be adequate as long as the attenuation is always greater than some minimum value, such as 45dB, for example. If you recall, the Chebyshev attenuation continued to rise with increasing frequency up to infinity, even though attenuation levels in excess of 60dB are of no practical use. In the Cauer response, the designer can specify the minimum stopband attenuation (*As*-min) actually needed for a particular application. Also, by properly selecting *Ap* and *As*-min, the attenuation peaks at *F4* and *F2* in Fig. 1.1 can be positioned near frequencies equal to two and three times the ripple cutoff frequency. This is useful when the second and third harmonics of an r.f. amplifier must be highly attenuated.

The abrupt attenuation rise in the Cauer response shown in Fig. 1.1 is due to resonant branches in the filter configuration, and this is one of the disadvantages of this filter type—careful tuning of the resonant circuits is required to obtain the expected response. The Cauer design is used whenever the transition band (the region between the end of the passband (*F-Ap*) and the start of the stopband (*F-As*)) must be minimised. Ratios of *F-As*/*F-Ap* for a minimum stopband attenuation of 40dB can vary from 1·1 for very selective filters to 1·8 or more for less selective filters.

TO BE CONTINUED

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2. O. Zobel, *Theory of Electric Wave Filters*, Bell Syst. Tech. Journ., January 1923.
3. R. Saal and E. Ulrich, *On the design of filters by synthesis*, *IRE Transactions on Circuit Theory*, December 1958.
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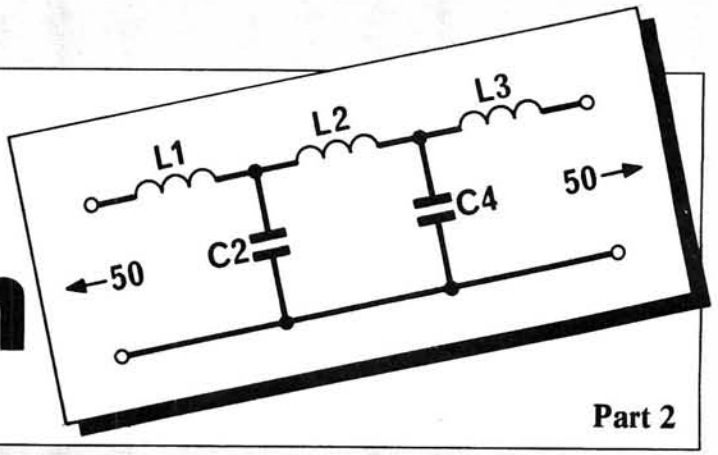

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Part 2

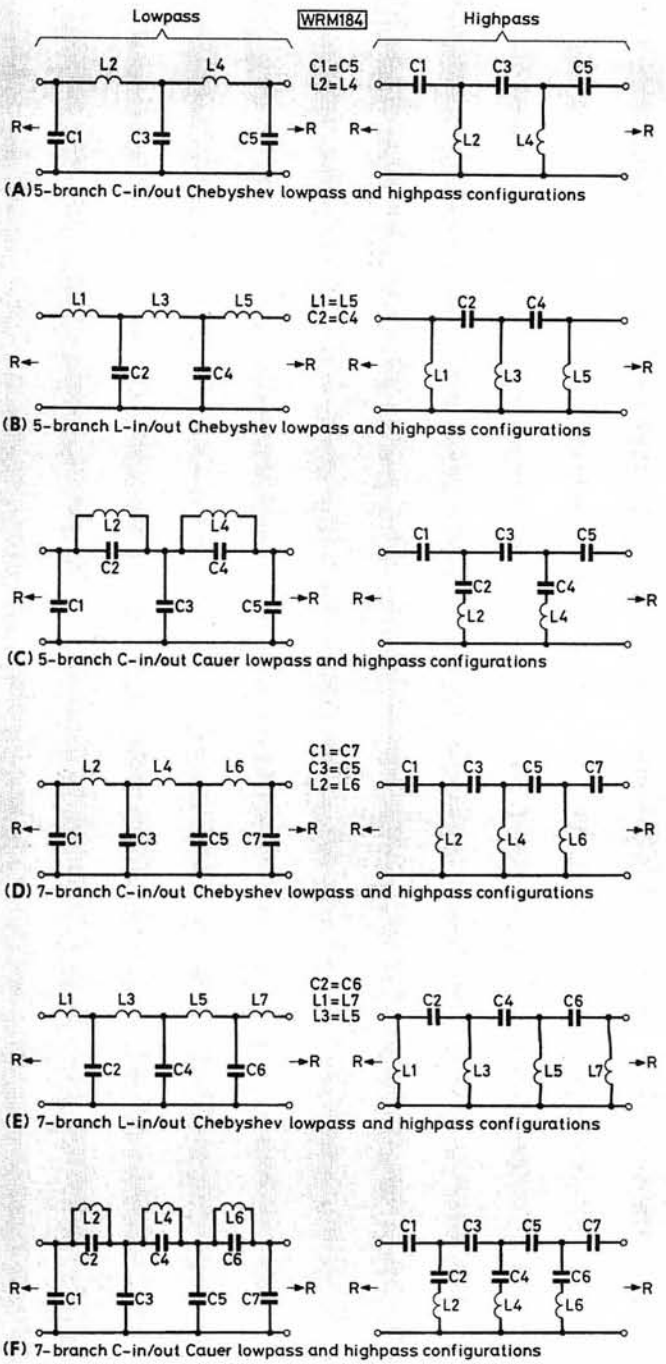
As explained last month, only the Chebyshev and Cauer responses are of interest for the filtering of sinusoidal waveforms encountered by the radio amateur. Consequently, the following discussion is concerned only with these two responses. Also, the number of filter elements, the number of different filter configurations and other characteristics will be limited to those most frequently needed by the radio amateur. Readers seeking more complicated filters are referred to the texts in the reference listing.

The Chebyshev and Cauer configurations most frequently needed by the radio amateur to form lowpass and highpass filters are shown in Fig. 2.1. These configurations are arranged in alternating shunt and series (or vice versa) branches numbered from left to right. The component (or components) in each branch is given the number of its branch for identification.

The filter theorist uses the term "degree" or "order" when defining the complexity of a filter, but for the amateur, the term "branch" is more meaningful. Thus, the filter configurations in Fig. 2.1(A) are 5-branch lowpass and highpass Chebyshev filters with capacitor input and output. Fig. 2.1(B) shows the same type except the input and output elements are inductive. Usually, capacitive input/output filters are preferred to minimise the number of inductors since inductors are usually more bulky, expensive and lossy than capacitors. However, occasionally the *L*-input lowpass filter is needed when the filter input impedance in the stopband must rise with increasing frequency. For example, some r.f. transistor amplifiers become unstable when terminated in a filter having a decreasing input impedance, such as with a *C*-input filter. In this case, an *L*-input filter may eliminate the instability[9].

The first branch in the filter configuration may be either shunt or series, and any number of branches may be used. Because the Chebyshev and Cauer designs with an odd number of branches have advantages over those with an even number, and because the 5- and 7-branch designs provide satisfactory filtering with a minimum of components, only these two types are considered. Chebyshev filters with an odd number of branches have repeating element values and odd-numbered Chebyshev and Cauer filters have equal termination impedances, thus simplifying construction.

The 5-branch Chebyshev filters provide about 6dB of attenuation per octave, per element, or about 30dB one octave from the cutoff frequency. A 5-branch filter is useful when only a moderate amount of attenuation is necessary. For example, the second harmonic of a Class A or B transistor r.f. amplifier is about 20dB below the fundamental, and a 5-branch Chebyshev lowpass filter will provide the additional attenuation needed for adequate harmonic



(A) 5-branch C-in/out Chebyshev lowpass and highpass configurations

(B) 5-branch L-in/out Chebyshev lowpass and highpass configurations

(C) 5-branch C-in/out Cauer lowpass and highpass configurations

(D) 7-branch C-in/out Chebyshev lowpass and highpass configurations

(E) 7-branch L-in/out Chebyshev lowpass and highpass configurations

(F) 7-branch C-in/out Cauer lowpass and highpass configurations

Fig. 2.1

reduction. Fig. 2.1(C) shows the Cauer 5-branch *C*-in/out lowpass and highpass configurations. The alternate Cauer *L*-in/out configuration is seldom used and is omitted. The components comprising the resonant circuits are associated with the similarly labelled attenuation peaks shown in Fig. 1.1 last month.

The 7-branch Chebyshev and Cauer lowpass and highpass configurations are shown in Fig. 2.1(D), (E) and (F). The comments on the 5-branch configurations also apply to the 7-branch configurations. The 7-branch Chebyshev configurations provide about 42dB of attenuation one octave from the cut-off frequency, and this filter type is frequently used to attenuate the harmonics of Class C transistor r.f. amplifiers[10]. The second harmonic level of a Class C transistor amplifier is only 10 to 15dB below the fundamental[11], and more attenuation is needed than that provided by the 5-branch filter. In this case, the more selective 7-branch Chebyshev or 5-branch Cauer is required.

The 7-branch Cauer provides both higher stopband attenuation and a narrower transition band as compared to all filters listed. A typical application of the 7-branch Cauer is the filtering of speech signals where an abrupt rise in attenuation is desired immediately following the cutoff frequency.

Calculation of Filter Component Values

After selecting the filter function (lowpass or highpass), response type (Chebyshev or Cauer), number of branches (5 or 7) and input element, the next step is to calculate the component values. This is normally accomplished by referring to tables of normalised lowpass filter designs that are available in many well-known references by Saal, Zverev, Geffe and others. These designs are normalised to an impedance of one ohm and a ripple cutoff frequency (*F-Ap*) of one radian per second, and all capacitances and inductances are in farads and henries. The Saal and Zverev tables are calculated for reflection coefficients of 1 to 5 per cent in 1 per cent steps, and for 8, 10, 15, 20, 25 and 50 per cent. Some references have normalised tables based on *Ap* values such as 0·01, 0·1, 0·25 and 0·5dB. These particular values of *rc* or *Ap* were used because they are nice round numbers, but any *rc* or *Ap* value within an appropriate range is equally suitable. To design a lowpass filter, a desired response is selected from the appropriate normalised table, and the lowpass component values are scaled to the cutoff frequency and impedance level selected by the user (equal source and load impedances are assumed). In the case of designing a highpass filter, the reciprocals of the lowpass normalised values are used to transform them into highpass values. Although this is a relatively simple arithmetic process, it causes problems to those unfamiliar with the procedure.

A 50 ohm lowpass filter is calculated for a ripple cutoff frequency (*F-Ap*) of 5·0MHz using the normalised lowpass values of Zverev for a *C*-input 7-branch Chebyshev design (see Fig. 2.1(D)) having a reflection coefficient of 1 per cent (from p.258 of [1]). The normalised C1, C3, L2 and L4 values are 0·5354F, 1·464F, 1·179H and 1·500H, respectively. Of course, these component values are ridiculously large, but they will become reasonable after they are scaled to the new impedance level and cutoff frequency.

The frequency and impedance scaling factors for inductance can be combined into one factor equal to $R/(6{\cdot}2832 \times f)$ where R is the source and load impedance in ohms and f is the ripple cutoff frequency in Hz. Thus, for a 50 ohm impedance level and a cutoff frequency of 5MHz, the inductance scaling factor is: $50/(6{\cdot}2832 \times 5 \times 10^6) = 1{\cdot}592 \times 10^{-6}$. In a similar way, the frequency and impedance scaling factors for capacitance can be combined into one factor. The capacitance scaling factor is: $1/(R \times 6{\cdot}2832 \times f)$. Thus, the *C*-scaling factor is: $1/(50 \times 6{\cdot}2832 \times 5 \times 10^6) = 636{\cdot}6 \times 10^{-12}$.

The normalised values are scaled to the desired cutoff frequency and impedance level by multiplying them by their scaling factors. Thus:

$L2 = L6 = 1{\cdot}179\text{H} \times 1{\cdot}592 \times 10^{-6} = 1{\cdot}877\mu\text{H}$,
$L4 = 1{\cdot}500\text{H} \times 1{\cdot}592 \times 10^{-6} = 2{\cdot}388\mu\text{H}$,
$C1 = C7 = 0{\cdot}5354\text{F} \times 636{\cdot}6 \times 10^{-12} = 340{\cdot}8\text{pF}$, and
$C3 = C5 = 1{\cdot}464\text{F} \times 636{\cdot}6 \times 10^{-12} = 932{\cdot}0\text{pF}$.

The fact that the inductance values are not standard values is of little concern because the inductors are usually hand-wound on powdered-iron toroidal cores with the proper number of turns to give the calculated inductance value. In comparison to the inductors, it is not feasible to hand-wind capacitors, and they must be purchased from an electronics distributor. The fact that the calculated C1, 3, 5 and 7 capacitor values are non-standard complicates the building of the filter.

Because of the established practice of using 20, 10 and 5 per cent tolerances in the electronic component industry, a series of capacitor values based on the 6th, 12th and 24th roots of ten has been adopted. For example, the 20 per cent series of standard values is: 10, 15, 22, 33, 47, 68 and 100. The 10 per cent series starts out with 10, 12, 15, 18, 22, etc. The 5 per cent series begins with 10, 11, 12, 13, 15, 16, 18, 20, 22, etc. It would be of considerable convenience to the radio amateur if only those filter designs requiring standard-value capacitors would be tabulated for easy selection. Obviously, the present standard design procedure using normalised tables is inappropriate for the radio amateur because it requires tables that may not be conveniently available, and it requires unfamiliar calculations that invariably result in designs with non-standard capacitor values.

A solution to this problem is to tabulate only those designs that are based on the capacitor standard values instead of on the *rc* values now used. This can be done by: 1. finding all the normalised designs that have the same capacitor ratio as the ratios of all the standard values, and: 2. using a cutoff frequency that causes the capacitors to have standard values. As a consequence, the *rc* values will be quite odd, but that is of no concern in this case.

By a fortunate coincidence, the 7-branch *C*-in/out Chebyshev design for *rc* = 1 per cent has a normalised *C*-ratio (1·464/0·5354 = 2·734), and this is virtually identical to the standard-value ratio of 820/300 = 2·7333. If the proper cutoff frequency is used, a standard-value capacitor (SVC) lowpass filter design could be calculated using the normalised values previously given. The reader is encouraged to explore this possibility by calculating a lowpass SVC design using a cutoff frequency of 5·68MHz.

A 7-element highpass filter with the configuration shown in Fig. 2.1(D) can be calculated by using the reciprocals of the previously given normalised lowpass values for C1, C3, L2 and L4. Thus, the normalised highpass component values for C1, C3, L2 and L4 are 1·868F, 0·6831F, 0·8482H and 0·6667H, respectively. The *rc* and other related parameters remain the same. An SVC highpass design can be calculated as previously demonstrated if an *F-Ap* cutoff frequency of 7·25MHz is selected.

By using a BASIC-programmed computer, many lowpass and highpass SVC filter design tables have been calculated for most of the filter configurations shown in

TABLE 2.1

ABBREVIATED LISTING OF 5-ELEMENT 50 OHM CHEBYSHEV SVC-FILTER DESIGNS

LOWPASS DESIGNS

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,5	L2,4	C3
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)
1	1.04	1.37	1.94	2.94	1.085	2200	9.82	4700
2	1.43	1.94	2.77	4.21	1.068	1500	6.96	3300
3	2.14	2.91	4.16	6.31	1.068	1000	4.64	2200
4	3.14	4.26	6.10	9.26	1.067	680	3.17	1500
5	4.91	6.45	9.13	13.8	1.087	470	2.09	1000
6	7.48	9.56	13.4	20.2	1.110	330	1.40	680
7	10.4	13.7	19.4	29.4	1.085	220	.981	470

HIGHPASS DESIGNS

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,5	L2,4	C3
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)
1	1.43	1.06	.738	.486	1.068	3300	4.44	1500
2	2.15	1.58	1.11	.730	1.068	2200	2.96	1000
3	3.17	2.33	1.63	1.07	1.067	1500	2.01	680
4	4.39	3.34	2.36	1.56	1.087	1000	1.41	470
5	6.03	4.72	3.36	2.23	1.110	680	1.00	330
6	9.43	7.15	5.04	3.33	1.085	470	.658	220

Fig. 2.1. In addition to tabulating the component values, the computer also calculated and tabulated the *F-Ap* cutoff frequencies and the frequencies of the 3, 20 and 40dB attenuation levels of the Chebyshev, and the *F3, F-As* and the frequencies of attenuation peaks for the Cauer filters. For example, Table 2.1 shows an abbreviated listing of 5-element 50 ohm lowpass and highpass Chebyshev SVC filter designs using the 20 per cent tolerance capacitor series and a selected v.s.w.r. limit of 1·110:1.

In the next part of this article, tables with many more designs will be presented for the Chebyshev family of SVC lowpass and highpass filters, in which the 5 per cent tolerance capacitor series is used. In this case, the increment in cutoff frequency from one design to the next is so small that virtually any cutoff frequency can be obtained by simply scanning the appropriate table for a suitable design and reading the design values directly. Because the radio amateur most frequently designs filters for a 1–10MHz decade and a 50 ohm impedance level, all designs are based on these values. However, a simple scaling procedure will be explained in which SVC designs for any frequency decade and any impedance level can be obtained while using the table in the "scan mode".

References

References 1–8 were listed in Part 1.
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10. E. Wetherhold, *Lowpass filters for attenuating r.f. amplifier harmonics*, Parts 1 and 2, *Short Wave Magazine*, December 1983 and January 1984.
11. M. F. "Doug" DeMaw, *On QRP Transmitters and Harmonic Output, SPRAT* (The Journal of the G-QRP Club), Nr. 35, Summer 1983.

APPENDIX A

The following equations relate the parameters associated with modern filter design.

1. $rc = 100 \times \sqrt{(1-0{\cdot}1^{x})}$
   where rc is reflection coefficient in per cent,
   $x = Ap/10$, and Ap = maximum passband attenuation in dB.

2. $Ap = -4{\cdot}3429 \times \log_e [1 - (rc/100)^2]$.
   See Equation 1 for explanation of terms.

3. v.s.w.r. $= [1 + (rc/100)]/[1 - (rc/100)]$.

4. $rc = 100 \times$ (v.s.w.r. $- 1$)/(v.s.w.r. $+ 1$).

5. $F3/F\text{-}Ap = 0{\cdot}5 \times (K + 1/K)$.
   where $K = (2/e)^{1/n}$
   where n = number of branches
   $e = p/\sqrt{(1 - p^2)}$, and $p = rc/100$
   Equation 5 is applicable for Chebyshev lowpass designs for $Ap < 0{\cdot}1$dB, $rc < 15\%$

For example, for $n = 5$, $rc = 6{\cdot}3\%$, $Ap = 0{\cdot}0172714$dB v.s.w.r. $= 1{\cdot}134$, $e = 0{\cdot}0631254$, $K = 1{\cdot}99602$ and $F3/F\text{-}Ap = 1{\cdot}2485$. If $F\text{-}Ap = 1{\cdot}462$MHz, then *F3* (lowpass) = 1·825MHz and *F3* (highpass) = 1·171MHz.

TO BE CONTINUED

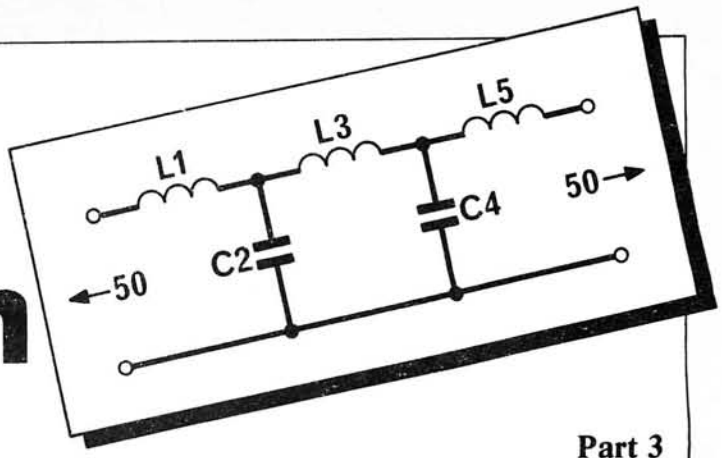
Did You Know...

That five of the world's great scientists huddled in a packing case to watch Marconi demonstrate his apparatus?

To discover whether his invention was suitable for communicating over water to lighthouses, Marconi set up his transmitter on the island of Flat Holme in the Bristol Channel, and his receiver three miles away on the Welsh coast at Lavernock Point. On 11 and 12 May 1897, before distinguished observers, the experiment was a failure. Sick with despair, Marconi accepted a suggestion that he remove his receiving apparatus from the cliff to the beach and so extend his 27 metre-high antenna vertically by a further 18m. On 14 May, during a storm, the five distinguished witnesses—including the celebrated Professor Slaby, who had been sent by the German Emperor—crammed themselves for shelter into a large packing case that had been laid on its side a few feet from the waves. To Marconi's relief, all went well, and he transmitted signals over the sea for the first time. Professor Slaby, describing the uncomfortable yet thrilling incident in his autobiography, wrote: "It will remain in my memory for ever."

Eric Westman

Practical LC Filter Design



by Edward Wetherhold W3NQN

Part 3

In the first part of this article, the difficulties involved in calculating the component values of a simple passive *LC* filter were explained. When the standard design procedures with normalised tables are used, calculation errors are easy to make and the resulting design invariably will have non-standard capacitor values which complicates the filter construction.

The solution to this problem is to use a new design procedure (the first major advancement in amateur radio passive *LC* filter design in the last twenty years) in which a filter is selected from tables of many precalculated standard-value capacitor (SVC) designs.

Comprehensive tables using 5, 10 and 20 per cent capacitor values are introduced in this article, and procedures will be explained whereby these tables may serve as a universal design aid for obtaining SVC filter designs for virtually any impedance level and any cutoff frequency. Using this new procedure, the radio amateur needs only to scan a few tables to find a suitable design. These SVC tables have been widely published in the US[10–22] and less extensively in the UK[23,24]. This article provides the first complete compilation of SVC filter tables for the UK reader.

Tables for SVC Filter Designs

The SVC tables in this article are for 5- and 7-element 50 ohm lowpass and highpass Chebyshev filters. These designs will satisfy most of the amateur filtering requirements. The more complicated and higher performance Cauer (elliptic) filters will be covered in a future article.

There are six SVC filter tables—four for lowpass and two for highpass (see Tables 3.1–3.6). Each table lists cutoff frequencies covering the 1–10MHz decade with sufficiently small increments so that virtually any cutoff frequency can be obtained. A schematic diagram and a typical attenuation response curve (or a reference to a curve) accompanies each table.

The four lowpass filter configurations consist of either capacitive or inductive input and output. The capacitive input/output configuration is usually preferred because it has a minimum number of inductors (see Tables 3.1 and 3.3). Inductors are usually more bulky, more costly and have higher losses than capacitors. However, there are occasions when bipolar transistor r.f. amplifiers become unstable when looking into a capacitive input filter. In this case, an inductive input/output filter may be necessary, and the designs in Tables 3.2 and 3.4 will be needed[9,14]. The two highpass filter tables are only for the capacitive input/output configuration. The alternative inductive input/output configuration is seldom required and it is therefore omitted.

The six tables of precalculated designs are all based on an impedance of 50 ohms because this impedance level is most frequently used in amateur radio applications. The 1–10MHz frequency range was used for listing the SVC data because it has conveniently tabulated values and the designs can be easily scaled to other decades by inspection.

Table Parameters

The design parameters for each filter are listed in columns. The first column is the identification number of a particular design. Thus, any filter in any of the six tables can be conveniently identified with its table number followed by a dash and its design identification number.

The next four columns list the frequencies at the filter cutoff and at the 3, 20 and 40dB attenuation levels on the filter response curve. This information is usually not available when designing with the customary normalised tables, and the inclusion of this stopband attenuation information in the SVC tables is another example of the convenience associated with this method of filter design.

The next column lists the maximum v.s.w.r. level of the filter design. These range from a minimum of 1·020 (corresponding to a reflection coefficient of 1·0 per cent) to a maximum of 1·273 (corresponding to a reflection

EDITOR'S NOTE

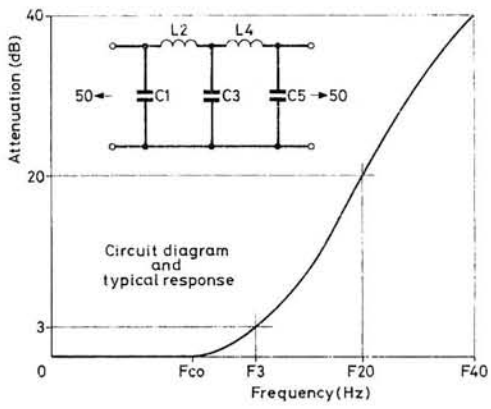
The tables in this article are based on the full E24 (5 per cent tolerance) range of capacitors, which are widely available in the US. On the UK hobbyist market, only the E12 (10 per cent tolerance) range of values appears to be available, although the capacitors offered have a tolerance of 5 per cent.

The intermediate values called for in the tables can of course be made up by paralleling appropriate values from the E12 series. For example, 1000pF and 100pF in parallel to produce 1100pF. The author recommends that this should **not** be done for cutoff frequencies above 30MHz because undesired interresonances between the paralleled capacitors may cause unexpected resonances in the filter stopband or passband. Below 30MHz, the paralleling of capacitors probably will present no problem, except for the additional cost and space required.

TABLE 3.1

5-ELEMENT 50-OHM, LOW-PASS CHEBYSHEV SVC-FILTER DESIGNS, CAPACITIVE INPUT, 5% TOLERANCE SERIES, SELECTED VSWR LIMIT = 1.273

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,5	L2,4	C3
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)
1	1.02	1.21	1.65	2.45	1.212	3000	10.7	5600
2	1.10	1.32	1.81	2.69	1.196	2700	9.88	5100
3	1.04	1.37	1.94	2.94	1.085	2200	9.82	4700
4	1.15	1.41	1.95	2.92	1.155	2400	9.37	4700
5	1.13	1.50	2.12	3.22	1.081	2000	9.00	4300
6	1.26	1.54	2.13	3.19	1.157	2200	8.56	4300
7	1.05	1.62	2.38	3.66	1.028	1600	8.35	3900
8	1.23	1.65	2.34	3.55	1.076	1800	8.19	3900
9	1.39	1.70	2.35	3.51	1.159	2000	7.75	3900
10	1.17	1.76	2.57	3.94	1.033	1500	7.70	3600
11	1.27	1.77	2.55	3.88	1.057	1600	7.64	3600
12	1.46	1.82	2.54	3.81	1.135	1800	7.28	3600
13	1.65	1.92	2.59	3.83	1.268	2000	6.64	3600
14	1.43	1.94	2.77	4.21	1.068	1500	6.96	3300
15	1.54	1.97	2.77	4.17	1.109	1600	6.79	3300
16	1.76	2.07	2.81	4.17	1.238	1800	6.21	3300
17	1.32	2.10	3.11	4.79	1.022	1200	6.42	3000
18	1.48	2.12	3.06	4.68	1.046	1300	6.39	3000
19	1.75	2.19	3.05	4.57	1.135	1500	6.07	3000
20	1.89	2.25	3.08	4.57	1.206	1600	5.77	3000
21	1.51	2.34	3.44	5.29	1.026	1100	5.78	2700
22	1.70	2.36	3.40	5.17	1.057	1200	5.73	2700
23	1.87	2.40	3.38	5.10	1.104	1300	5.57	2700
24	2.20	2.56	3.46	5.11	1.268	1500	4.98	2700
25	1.75	2.63	3.85	5.91	1.033	1000	5.14	2400
26	1.99	2.67	3.81	5.78	1.072	1100	5.05	2400
27	2.19	2.74	3.81	5.71	1.135	1200	4.85	2400
28	2.40	2.84	3.86	5.73	1.227	1300	4.55	2400
29	1.89	2.87	4.21	6.46	1.030	910	4.71	2200
30	2.14	2.91	4.16	6.31	1.068	1000	4.64	2200
31	2.39	2.99	4.16	6.23	1.135	1100	4.45	2200
32	2.64	3.11	4.22	6.25	1.238	1200	4.14	2200
33	2.05	3.16	4.64	7.13	1.028	820	4.28	2000
34	2.36	3.20	4.57	6.94	1.068	910	4.22	2000
35	2.63	3.28	4.57	6.86	1.135	1000	4.05	2000
36	2.93	3.43	4.65	6.89	1.251	1100	3.73	2000
37	2.34	3.51	5.14	7.88	1.033	750	3.85	1800
38	2.63	3.56	5.08	7.71	1.069	820	3.79	1800
39	2.96	3.66	5.09	7.62	1.145	910	3.61	1800
40	3.30	3.84	5.19	7.67	1.268	1000	3.32	1800
41	2.70	3.96	5.76	8.82	1.039	680	3.42	1600
42	3.06	4.03	5.71	8.63	1.086	750	3.34	1600
43	3.38	4.14	5.73	8.57	1.159	820	3.18	1600
44	2.77	4.21	6.18	9.48	1.030	620	3.21	1500
45	3.14	4.26	6.10	9.26	1.067	680	3.17	1500
46	3.51	4.38	6.10	9.14	1.135	750	3.03	1500
47	3.88	4.56	6.20	9.17	1.241	820	2.82	1500
48	3.39	4.88	7.08	10.8	1.044	560	2.77	1300
49	3.84	4.98	7.02	10.6	1.097	620	2.70	1300
50	4.26	5.14	7.08	10.5	1.181	680	2.55	1300
51	3.61	5.28	7.68	11.8	1.039	510	2.56	1200
52	4.06	5.36	7.61	11.5	1.083	560	2.51	1200
53	4.55	5.54	7.65	11.4	1.167	620	2.37	1200
54	3.96	5.76	8.38	12.8	1.041	470	2.35	1100
55	4.39	5.84	8.31	12.6	1.079	510	2.31	1100
56	4.88	6.01	8.33	12.5	1.152	560	2.20	1100
57	4.40	6.34	9.20	14.1	1.043	430	2.13	1000
58	4.91	6.45	9.13	13.8	1.087	470	2.09	1000
59	5.38	6.62	9.17	13.7	1.154	510	2.00	1000
60	4.81	6.97	10.1	15.5	1.042	390	1.94	910
61	5.43	7.09	10.0	15.2	1.091	430	1.89	910
62	6.00	7.31	10.1	15.1	1.167	470	1.80	910
63	4.86	7.69	11.4	17.5	1.023	330	1.76	820
64	5.51	7.76	11.2	17.1	1.052	360	1.74	820
65	6.07	7.89	11.1	16.8	1.095	390	1.70	820
66	6.77	8.17	11.2	16.7	1.184	430	1.60	820
67	5.26	8.40	12.4	19.2	1.022	300	1.61	750
68	6.04	8.48	12.2	18.7	1.052	330	1.59	750
69	6.70	8.64	12.2	18.4	1.101	360	1.55	750
70	7.33	8.89	12.3	18.3	1.175	390	1.48	750
71	6.69	9.36	13.5	20.6	1.054	300	1.44	680
72	7.48	9.56	13.4	20.2	1.110	330	1.40	680
73	8.25	9.89	13.6	20.2	1.196	360	1.32	680
74	7.21	10.2	14.8	22.6	1.048	270	1.32	620
75	8.18	10.5	14.7	22.2	1.107	300	1.28	620
76	9.11	10.9	14.9	22.1	1.203	330	1.20	620
77	7.82	11.3	16.4	25.1	1.042	240	1.20	560
78	9.02	11.6	16.3	24.6	1.105	270	1.15	560
79	10.2	12.1	16.5	24.5	1.212	300	1.07	560
80	8.66	12.4	18.0	27.6	1.044	220	1.09	510
81	9.64	12.6	17.9	27.1	1.088	240	1.06	510
82	9.22	13.5	19.6	30.0	1.039	200	1.00	470
83	10.4	13.7	19.4	29.4	1.085	220	.981	470
84	9.85	14.7	21.5	33.0	1.034	180	.919	430
85	10.5	16.2	23.8	36.6	1.028	160	.835	390

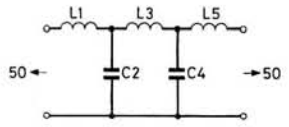


coefficient of 12 per cent). This range of v.s.w.r. was considered to be adequate for amateur radio applications. Filter designs with smaller values of v.s.w.r. have too gradual a rise in attenuation for effective filtering, and therefore designs for v.s.w.r. values less than 1·020 are omitted. Designs with v.s.w.r.s greater than 1·273 are omitted because they are not appropriate for r.f. filtering requirements where low v.s.w.r. characteristics are important. In my *Short Wave Magazine* article, "Low-pass filters for attenuating r.f. amplifier harmonics, Part 1"[24], I recommended the v.s.w.r. should not exceed 1·1; however, in order to increase the number of usable designs, I have

TABLE 3.2

5-ELEMENT 50-OHM, LOW-PASS CHEBYSHEV SVC-FILTER DESIGNS, INDUCTIVE INPUT, 5% TOLERANCE SERIES, SELECTED VSWR LIMIT = 1.273

NO.	-----FREQUENCY (MHZ)-----				MAX.	L1,5	C2,4	L3
	F-CO	3-DB	20DB	40DB	VSWR	(UH)	(PF)	(UH)
1	.74	1.15	1.69	2.60	1.027	5.60	4700	13.72
2	.90	1.26	1.81	2.76	1.055	5.60	4300	12.66
3	1.06	1.38	1.94	2.93	1.096	5.60	3900	11.75
4	1.19	1.47	2.05	3.07	1.138	5.60	3600	11.15
5	1.32	1.58	2.17	3.23	1.192	5.60	3300	10.61
6	1.46	1.70	2.30	3.41	1.260	5.60	3000	10.12
7	.91	1.39	2.03	3.12	1.030	4.70	3900	11.38
8	1.08	1.50	2.16	3.29	1.056	4.70	3600	10.60
9	1.25	1.63	2.30	3.48	1.092	4.70	3300	9.92
10	1.42	1.77	2.46	3.68	1.142	4.70	3000	9.32
11	1.61	1.92	2.63	3.90	1.209	4.70	2700	8.79
12	1.05	1.64	2.41	3.72	1.025	3.90	3300	9.63
13	1.29	1.80	2.60	3.96	1.054	3.90	3000	8.83
14	1.54	1.99	2.80	4.22	1.099	3.90	2700	8.15
15	1.80	2.19	3.03	4.53	1.164	3.90	2400	7.57
16	1.99	2.35	3.20	4.75	1.222	3.90	2200	7.23
17	1.34	2.00	2.93	4.49	1.034	3.30	2700	7.89
18	1.68	2.25	3.20	4.84	1.077	3.30	2400	7.15
19	1.92	2.43	3.40	5.11	1.118	3.30	2200	6.72
20	2.16	2.63	3.62	5.40	1.174	3.30	2000	6.35
21	2.43	2.85	3.87	5.72	1.247	3.30	1800	6.02
22	1.66	2.46	3.59	5.51	1.035	2.70	2200	6.43
23	1.99	2.70	3.86	5.85	1.069	2.70	2000	5.93
24	2.34	2.97	4.15	6.24	1.118	2.70	1800	5.50
25	2.71	3.27	4.49	6.68	1.188	2.70	1600	5.13
26	2.92	3.43	4.67	6.92	1.233	2.70	1500	4.97
27	2.01	3.01	4.39	6.74	1.034	2.20	1800	5.26
28	2.52	3.37	4.80	7.27	1.077	2.20	1600	4.76
29	2.78	3.57	5.02	7.56	1.107	2.20	1500	4.55
30	3.34	4.02	5.52	8.21	1.190	2.20	1300	4.18
31	3.65	4.27	5.80	8.58	1.247	2.20	1200	4.01
32	2.35	3.61	5.29	8.14	1.029	1.80	1500	4.38
33	3.12	4.14	5.89	8.92	1.080	1.80	1300	3.88
34	3.51	4.45	6.23	9.36	1.118	1.80	1200	3.67
35	3.93	4.78	6.60	9.85	1.169	1.80	1100	3.48
36	4.37	5.15	7.01	10.39	1.233	1.80	1000	3.31
37	3.10	4.51	6.56	10.03	1.041	1.50	1200	3.51
38	3.65	4.90	6.99	10.60	1.073	1.50	1100	3.27
39	4.21	5.34	7.47	11.23	1.118	1.50	1000	3.06
40	4.75	5.77	7.95	11.86	1.173	1.50	910	2.89
41	5.34	6.26	8.49	12.57	1.245	1.50	820	2.74
42	3.53	5.41	7.94	12.20	1.029	1.20	1000	2.92
43	4.30	5.94	8.53	12.98	1.060	1.20	910	2.68
44	5.09	6.53	9.18	13.84	1.106	1.20	820	2.49
45	5.73	7.04	9.75	14.58	1.155	1.20	750	2.35
46	6.42	7.61	10.38	15.41	1.219	1.20	680	2.23
47	4.40	6.60	9.65	14.80	1.033	1.00	820	2.39
48	5.27	7.20	10.32	15.68	1.064	1.00	750	2.22
49	6.15	7.87	11.06	16.65	1.108	1.00	680	2.06
50	6.95	8.51	11.76	17.58	1.160	1.00	620	1.95
51	7.80	9.22	12.55	18.61	1.227	1.00	560	1.85
52	5.23	7.96	11.67	17.92	1.030	.82	680	1.99
53	6.33	8.72	12.51	19.03	1.061	.82	620	1.83
54	7.45	9.56	13.45	20.26	1.106	.82	560	1.70
55	8.44	10.35	14.32	21.40	1.158	.82	510	1.60
56	9.28	11.04	15.09	22.41	1.211	.82	470	1.53
57	6.41	9.66	14.15	21.71	1.032	.68	560	1.64
58	7.75	10.59	15.18	23.06	1.064	.68	510	1.51
59	8.83	11.41	16.08	24.25	1.100	.68	470	1.42
60	9.97	12.31	17.08	25.56	1.148	.68	430	1.34

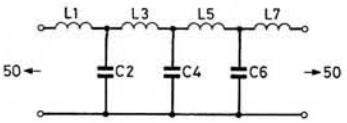


See Table 3.1 for typical response

TABLE 3.4

7-ELEMENT 50-OHM, LOW-PASS CHEBYSHEV SVC-FILTER DESIGNS, INDUCTIVE INPUT, 5% TOLERANCE SERIES, SELECTED VSWR LIMIT = 1.273

NO.	-----FREQUENCY (MHZ)-----				MAX.	L1,L7	C2,C6	L3,L5	C4
	F-CO	3-DB	20DB	40DB	VSWR	(UH)	(PF)	(UH)	(PF)
1	1.01	1.18	1.44	1.87	1.081	5.89	4300	13.4	5100
2	1.09	1.29	1.60	2.08	1.059	5.06	3900	12.0	4700
3	1.20	1.40	1.73	2.24	1.071	4.81	3600	11.2	4300
4	1.33	1.54	1.88	2.43	1.087	4.58	3300	10.3	3900
5	1.42	1.68	2.07	2.70	1.064	3.95	3000	9.27	3600
6	1.53	1.85	2.31	3.02	1.045	3.36	2700	8.32	3300
7	1.63	2.06	2.59	3.41	1.029	2.83	2400	7.41	3000
8	1.86	2.27	2.83	3.70	1.042	2.71	2200	6.78	2700
9	1.91	2.07	2.46	3.12	1.238	4.31	2400	8.19	2700
10	2.14	2.52	3.11	4.04	1.064	2.63	2000	6.18	2400
11	2.29	2.78	3.46	4.52	1.045	2.24	1800	5.54	2200
12	2.45	3.09	3.88	5.11	1.029	1.89	1600	4.94	2000
13	2.85	3.37	4.15	5.39	1.064	1.97	1500	4.64	1800
14	2.86	3.11	3.69	4.68	1.238	2.88	1600	5.46	1800
15	3.13	3.84	4.79	6.27	1.039	1.59	1300	4.00	1600
16	3.27	4.12	5.18	6.81	1.029	1.41	1200	3.70	1500
17	3.47	3.90	4.70	6.02	1.140	2.00	1300	4.17	1500
18	3.99	4.61	5.64	7.28	1.087	1.53	1100	3.43	1300
19	4.27	5.05	6.22	8.09	1.064	1.32	1000	3.09	1200
20	4.63	5.53	6.85	8.91	1.056	1.17	910	2.81	1100
21	5.05	6.11	7.60	9.92	1.047	1.03	820	2.53	1000
22	5.58	6.70	8.31	10.8	1.052	.953	750	2.31	910
23	6.23	7.41	9.16	11.9	1.059	.880	680	2.10	820
24	6.79	8.12	10.0	13.1	1.055	.795	620	1.91	750
25	7.46	8.97	11.1	14.5	1.051	.710	560	1.73	680
26	8.18	9.85	12.2	15.9	1.050	.644	510	1.57	620
27	9.21	10.8	13.2	17.1	1.074	.633	470	1.46	560
28	10.1	11.8	14.4	18.7	1.081	.589	430	1.34	510
29	10.9	12.9	16.0	20.8	1.059	.506	390	1.20	470

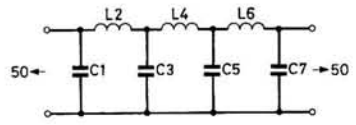


See Table 3.1 for typical response

TABLE 3.3

7-ELEMENT 50-OHM, LOW-PASS CHEBYSHEV SVC-FILTER DESIGNS, CAPACITIVE INPUT, 5% TOLERANCE SERIES, SELECTED VSWR LIMIT = 1.273

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,7	L2,6	C3,5	L4
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)	(UH)
1	1.02	1.10	1.31	1.65	1.254	3300	11.2	6200	12.6
2	1.04	1.16	1.40	1.79	1.142	2700	10.9	5600	12.6
3	1.13	1.23	1.45	1.84	1.264	3000	10.1	5600	11.3
4	1.05	1.23	1.51	1.96	1.071	2200	10.3	5100	12.3
5	1.12	1.26	1.53	1.96	1.123	2400	10.0	5100	11.7
6	1.23	1.34	1.59	2.01	1.247	2700	9.29	5100	10.4
7	1.03	1.30	1.63	2.15	1.030	1800	9.52	4700	11.9
8	1.12	1.33	1.64	2.13	1.064	2000	9.50	4700	11.4
9	1.21	1.37	1.66	2.13	1.119	2200	9.27	4700	10.8
10	1.29	1.42	1.70	2.16	1.200	2400	8.82	4700	10.0
11	1.10	1.41	1.79	2.36	1.023	1600	8.68	4300	11.0
12	1.21	1.45	1.79	2.33	1.058	1800	8.71	4300	10.5
13	1.31	1.49	1.81	2.33	1.114	2000	8.50	4300	9.91
14	1.42	1.56	1.86	2.36	1.202	2200	8.06	4300	9.14
15	1.25	1.57	1.97	2.59	1.031	1500	7.90	3900	9.85
16	1.32	1.59	1.97	2.57	1.050	1600	7.91	3900	9.62
17	1.44	1.64	1.99	2.56	1.109	1800	7.73	3900	9.04
18	1.57	1.72	2.05	2.60	1.205	2000	7.30	3900	8.27
19	1.44	1.73	2.14	2.78	1.056	1500	7.29	3600	8.82
20	1.52	1.76	2.15	2.78	1.086	1600	7.22	3600	8.54
21	1.66	1.84	2.20	2.81	1.176	1800	6.86	3600	7.83
22	1.51	1.86	2.33	3.05	1.037	1300	6.69	3300	8.27
23	1.68	1.93	2.35	3.03	1.099	1500	6.58	3300	7.72
24	1.77	1.98	2.38	3.05	1.147	1600	6.40	3300	7.37
25	1.56	2.02	2.56	3.38	1.021	1100	6.04	3000	7.68
26	1.68	2.05	2.56	3.35	1.042	1200	6.09	3000	7.47
27	1.79	2.09	2.57	3.33	1.073	1300	6.05	3000	7.21
28	1.99	2.20	2.64	3.37	1.176	1500	5.72	3000	6.52
29	2.11	2.28	2.70	3.42	1.257	1600	5.42	3000	6.08
30	1.75	2.25	2.84	3.75	1.023	1000	5.45	2700	6.89
31	1.89	2.29	2.84	3.71	1.048	1100	5.48	2700	6.68
32	2.02	2.34	2.86	3.70	1.086	1200	5.41	2700	6.40
33	2.15	2.41	2.90	3.72	1.141	1300	5.26	2700	6.06
34	2.01	2.54	3.20	4.21	1.027	910	4.86	2400	6.09
35	2.17	2.59	3.20	4.17	1.056	1000	4.86	2400	5.88
36	2.33	2.66	3.24	4.17	1.104	1100	4.77	2400	5.59
37	2.49	2.76	3.30	4.21	1.176	1200	4.57	2400	5.22
38	2.16	2.76	3.49	4.60	1.024	820	4.44	2200	5.61
39	2.35	2.82	3.49	4.55	1.053	910	4.46	2200	5.41
40	2.52	2.89	3.52	4.54	1.099	1000	4.38	2200	5.15
41	2.72	3.01	3.60	4.59	1.176	1100	4.19	2200	4.78
42	2.38	3.04	3.84	5.06	1.025	750	4.04	2000	5.09
43	2.57	3.09	3.84	5.01	1.050	820	4.06	2000	4.93
44	2.78	3.18	3.88	5.00	1.100	910	3.99	2000	4.68
45	2.99	3.31	3.96	5.05	1.176	1000	3.81	2000	4.35
46	2.67	3.38	4.26	5.61	1.027	680	3.64	1800	4.57
47	2.89	3.45	4.27	5.56	1.056	750	3.65	1800	4.41
48	3.09	3.54	4.31	5.55	1.100	820	3.59	1800	4.21
49	3.35	3.69	4.42	5.62	1.188	910	3.40	1800	3.87
50	3.07	3.82	4.80	6.30	1.033	620	3.24	1600	4.03
51	3.30	3.90	4.81	6.25	1.064	680	3.24	1600	3.88
52	3.55	4.02	4.87	6.26	1.120	750	3.15	1600	3.67
53	3.81	4.19	4.99	6.34	1.204	820	3.00	1600	3.39
54	3.17	4.05	5.12	6.75	1.024	560	3.03	1500	3.82
55	3.45	4.13	5.12	6.68	1.053	620	3.04	1500	3.69
56	3.69	4.24	5.17	6.66	1.097	680	2.99	1500	3.51
57	3.99	4.41	5.28	6.73	1.176	750	2.86	1500	3.26
58	3.81	4.72	5.90	7.74	1.036	510	2.64	1300	3.26
59	4.10	4.82	5.93	7.69	1.070	560	2.62	1300	3.14
60	4.43	4.98	6.02	7.72	1.133	620	2.54	1300	2.94
61	4.78	5.21	6.19	7.85	1.230	680	2.39	1300	2.70
62	4.13	5.11	6.39	8.38	1.035	470	2.43	1200	3.01
63	4.40	5.20	6.41	8.33	1.064	510	2.43	1200	2.91
64	4.72	5.35	6.49	8.34	1.116	560	2.37	1200	2.76
65	5.12	5.60	6.67	8.48	1.214	620	2.23	1200	2.52
66	4.49	5.57	6.98	9.15	1.035	430	2.23	1100	2.76
67	4.82	5.68	7.00	9.09	1.066	470	2.22	1100	2.66
68	5.12	5.83	7.07	9.10	1.112	510	2.18	1100	2.54
69	5.52	6.07	7.24	9.21	1.196	560	2.07	1100	2.35
70	4.93	6.12	7.67	10.1	1.034	390	2.03	1000	2.51
71	5.33	6.26	7.70	10.0	1.069	430	2.02	1000	2.41
72	5.69	6.44	7.80	10.0	1.122	470	1.97	1000	2.29
73	6.08	6.68	7.97	10.1	1.198	510	1.88	1000	2.13
74	5.49	6.75	8.43	11.0	1.038	360	1.85	910	2.28
75	5.84	6.87	8.46	11.0	1.068	390	1.84	910	2.20
76	6.28	7.09	8.58	11.0	1.126	430	1.79	910	2.07
77	6.75	7.39	8.80	11.2	1.213	470	1.69	910	1.91
78	5.68	7.39	9.37	12.4	1.020	300	1.65	820	2.10
79	6.17	7.52	9.36	12.2	1.043	330	1.66	820	2.04
80	6.60	7.68	9.41	12.2	1.079	360	1.65	820	1.96
81	7.01	7.89	9.53	12.2	1.131	390	1.61	820	1.86
82	7.59	8.27	9.82	12.5	1.233	430	1.51	820	1.70
83	6.72	8.21	10.2	13.4	1.042	300	1.52	750	1.87
84	7.23	8.40	10.3	13.3	1.080	330	1.51	750	1.79
85	7.72	8.66	10.4	13.4	1.138	360	1.46	750	1.69
86	8.24	9.00	10.7	13.6	1.222	390	1.39	750	1.57
87	7.36	9.04	11.3	14.8	1.039	270	1.38	680	1.70
88	7.98	9.27	11.4	14.7	1.082	300	1.37	680	1.62
89	8.58	9.59	11.6	14.8	1.148	330	1.32	680	1.52
90	9.23	10.0	11.9	15.1	1.247	360	1.24	680	1.39
91	7.91	9.86	12.4	16.2	1.032	240	1.26	620	1.56
92	8.67	10.1	12.4	16.1	1.075	270	1.25	620	1.49
93	9.39	10.5	12.7	16.2	1.145	300	1.20	620	1.39
94	10.2	11.0	13.1	16.5	1.254	330	1.12	620	1.26
95	8.86	11.0	13.7	18.0	1.036	220	1.13	560	1.40
96	9.49	11.2	13.8	17.8	1.068	240	1.13	560	1.35
97	10.4	11.6	14.0	17.9	1.142	270	1.09	560	1.26
98	9.72	12.0	15.0	19.7	1.036	200	1.03	510	1.28
99	10.5	12.3	15.1	19.6	1.071	220	1.03	510	1.23
100	10.3	13.0	16.3	21.5	1.030	180	.951	470	1.19



See Table 3.1 for typical response

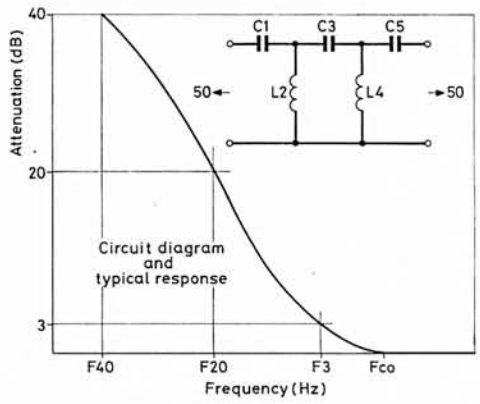
raised the upper limit on the v.s.w.r. parameter to 1·273. The corresponding range of maximum passband attenuation ripple amplitudes are 0·000434 and 0·0630dB. The v.s.w.r. fluctuates in the filter passband between 1·000 and

◀ Table 3.4 on facing page

TABLE 3.5

5-ELEMENT 50-OHM, HIGH-PASS CHEBYSHEV SVC-FILTER DESIGNS, CAPACITIVE INPUT, 5% TOLERANCE SERIES, SELECTED VSWR LIMIT = 1.273

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,5	L2,4	C3
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)
1	1.04	.726	.501	.328	1.044	5100	0.45	2200
2	1.04	.788	.554	.366	1.081	4300	5.97	2000
3	1.17	.800	.550	.359	1.039	4700	5.85	2000
4	1.07	.857	.615	.410	1.135	3600	5.56	1800
5	1.17	.877	.616	.406	1.076	3900	5.36	1800
6	1.33	.890	.609	.397	1.034	4300	5.26	1800
7	1.12	.938	.686	.461	1.206	3000	5.20	1600
8	1.25	.974	.693	.461	1.109	3300	4.86	1600
9	1.36	.994	.691	.454	1.057	3600	4.71	1600
10	1.54	1.00	.683	.444	1.028	3900	4.67	1600
11	1.14	.978	.723	.490	1.268	2700	5.09	1500
12	1.28	1.03	.738	.492	1.135	3000	4.64	1500
13	1.43	1.06	.738	.486	1.068	3300	4.44	1500
14	1.61	1.07	.730	.476	1.033	3600	4.38	1500
15	1.35	1.14	.841	.567	1.227	2400	4.29	1300
16	1.55	1.20	.853	.566	1.104	2700	3.94	1300
17	1.75	1.23	.848	.555	1.046	3000	3.81	1300
18	1.45	1.24	.909	.614	1.238	2200	3.99	1200
19	1.60	1.29	.923	.616	1.135	2400	3.71	1200
20	1.84	1.32	.921	.605	1.057	2700	3.54	1200
21	2.14	1.34	.906	.587	1.022	3000	3.50	1200
22	1.57	1.34	.989	.669	1.251	2000	3.69	1100
23	1.75	1.40	1.01	.672	1.135	2200	3.40	1100
24	1.93	1.44	1.01	.664	1.072	2400	3.27	1100
25	2.27	1.46	.992	.645	1.026	2700	3.21	1100
26	1.71	1.47	1.08	.734	1.268	1800	3.39	1000
27	1.93	1.54	1.11	.739	1.135	2000	3.09	1000
28	2.15	1.58	1.11	.730	1.068	2200	2.96	1000
29	2.41	1.60	1.10	.714	1.033	2400	2.92	1000
30	2.09	1.69	1.22	.812	1.145	1800	2.83	910
31	2.36	1.74	1.22	.802	1.068	2000	2.70	910
32	2.68	1.76	1.20	.783	1.030	2200	2.66	910
33	2.12	1.81	1.33	.898	1.241	1500	2.73	820
34	2.28	1.86	1.35	.902	1.159	1600	2.58	820
35	2.61	1.93	1.35	.890	1.069	1800	2.43	820
36	3.01	1.96	1.33	.866	1.028	2000	2.39	820
37	2.57	2.06	1.48	.985	1.135	1500	2.32	750
38	2.76	2.10	1.48	.978	1.086	1600	2.25	750
39	3.21	2.14	1.46	.952	1.033	1800	2.19	750
40	2.69	2.23	1.62	1.09	1.181	1300	2.17	680
41	3.17	2.33	1.63	1.07	1.067	1500	2.01	680
42	3.44	2.35	1.62	1.06	1.039	1600	1.99	680
43	2.99	2.46	1.78	1.19	1.167	1200	1.96	620
44	3.27	2.53	1.79	1.19	1.097	1300	1.87	620
45	3.93	2.59	1.76	1.15	1.030	1500	1.81	620
46	3.37	2.74	1.97	1.32	1.152	1100	1.75	560
47	3.72	2.81	1.98	1.31	1.083	1200	1.67	560
48	4.10	2.85	1.97	1.29	1.044	1300	1.64	560
49	3.69	3.00	2.17	1.45	1.154	1000	1.60	510
50	4.11	3.09	2.17	1.44	1.079	1100	1.52	510
51	4.59	3.14	2.15	1.41	1.039	1200	1.49	510
52	3.95	3.24	2.35	1.57	1.167	910	1.49	470
53	4.39	3.34	2.36	1.56	1.087	1000	1.41	470
54	4.94	3.40	2.34	1.53	1.041	1100	1.38	470
55	4.24	3.52	2.56	1.72	1.184	820	1.38	430
56	4.77	3.65	2.58	1.71	1.091	910	1.29	430
57	5.36	3.71	2.56	1.67	1.043	1000	1.26	430
58	4.72	3.89	2.83	1.90	1.175	750	1.24	390
59	5.22	4.02	2.84	1.88	1.095	820	1.17	390
60	5.93	4.10	2.82	1.85	1.042	910	1.14	390
61	5.01	4.18	3.05	2.05	1.196	680	1.16	360
62	5.60	4.34	3.08	2.04	1.101	750	1.09	360
63	6.23	4.42	3.07	2.01	1.052	820	1.06	360
64	5.44	4.55	3.33	2.24	1.203	620	1.07	330
65	6.03	4.72	3.36	2.23	1.110	680	1.00	330
66	6.78	4.82	3.35	2.20	1.052	750	.970	330
67	7.70	4.87	3.30	2.14	1.023	820	.962	330
68	5.94	4.99	3.65	2.46	1.212	560	.978	300
69	6.66	5.20	3.70	2.46	1.107	620	.910	300
70	7.43	5.31	3.68	2.42	1.054	680	.882	300
71	8.56	5.36	3.62	2.35	1.022	750	.875	300
72	6.69	5.58	4.07	2.74	1.196	510	.870	270
73	7.43	5.78	4.11	2.73	1.105	560	.817	270
74	8.39	5.91	4.08	2.68	1.048	620	.792	270
75	7.84	6.38	4.61	3.08	1.155	470	.752	240
76	8.59	6.55	4.62	3.06	1.088	510	.719	240
77	9.64	6.66	4.58	3.00	1.042	560	.702	240
78	8.53	6.95	5.02	3.36	1.157	430	.690	220
79	9.43	7.15	5.04	3.33	1.085	470	.658	220
80	10.4	7.26	5.01	3.28	1.044	510	.644	220
81	8.53	7.33	5.42	3.67	1.268	360	.678	200
82	9.36	7.64	5.52	3.70	1.159	390	.628	200
83	10.4	7.88	5.54	3.66	1.081	430	.596	200
84	9.69	8.24	6.06	4.09	1.238	330	.597	180
85	10.7	8.57	6.15	4.10	1.135	360	.556	180



the maximum value listed for each design. Normally, it is not necessary to know the exact value of v.s.w.r. for a particular passband frequency because it is sufficient to know that it will never exceed a particular maximum value.

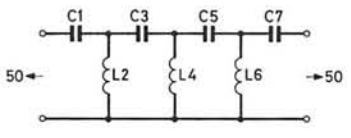
The concluding columns list the filter component values in picofarads (pF) and microhenries (μH). In all the tables, all capacitor listings are standard values. All inductor values are whatever values are required to cause the capacitor values to be standard, except for Table 3.2 where the advantage of standard values is also extended to inductors L1 and L5. The fact that most of the inductor values are non-standard presents no problem because

TABLE 3.6

7-ELEMENT 50-OHM, HIGH-PASS CHEBYSHEV SVC-FILTER DESIGNS, CAPACITIVE INPUT, 5% TOLERANCE SERIES, SELECTED VSWR LIMIT = 1.273

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,7	L2,6	C3,5	L4
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)	(UH)
1	1.02	.826	.660	.504	1.036	5100	6.16	2000	4.98
2	1.00	.880	.724	.563	1.109	3900	5.67	1800	4.80
3	1.08	.905	.732	.563	1.058	4300	5.55	1800	4.60
4	1.16	.922	.734	.558	1.030	4700	5.55	1800	4.45
5	1.00	.924	.780	.617	1.257	3000	5.53	1600	4.93
6	1.09	.971	.806	.630	1.147	3300	5.15	1600	4.48
7	1.16	1.00	.819	.634	1.086	3600	4.99	1600	4.22
8	1.23	1.02	.824	.632	1.050	3900	4.93	1600	4.06
9	1.34	1.04	.825	.625	1.023	4300	4.95	1600	3.92
10	1.13	1.02	.853	.669	1.176	3000	4.92	1500	4.31
11	1.22	1.06	.871	.676	1.099	3300	4.70	1500	4.01
12	1.30	1.09	.879	.675	1.056	3600	4.63	1500	3.83
13	1.39	1.11	.880	.670	1.031	3900	4.63	1500	3.71
14	1.34	1.20	.994	.776	1.141	2700	4.17	1300	3.62
15	1.45	1.24	1.01	.780	1.073	3000	4.03	1300	3.38
16	1.57	1.27	1.02	.775	1.037	3300	4.00	1300	3.24
17	1.41	1.28	1.07	.836	1.176	2400	3.94	1200	3.45
18	1.55	1.34	1.09	.845	1.086	2700	3.74	1200	3.16
19	1.68	1.37	1.10	.841	1.042	3000	3.70	1200	3.01
20	1.54	1.39	1.16	.912	1.176	2200	3.61	1100	3.16
21	1.65	1.44	1.19	.921	1.104	2400	3.46	1100	2.95
22	1.80	1.49	1.20	.919	1.048	2700	3.39	1100	2.78
23	1.97	1.52	1.20	.908	1.021	3000	3.41	1099	2.68
24	1.70	1.53	1.28	1.00	1.176	2000	3.28	1000	2.87
25	1.82	1.59	1.31	1.01	1.099	2200	3.14	1000	2.67
26	1.95	1.63	1.32	1.01	1.056	2400	3.08	1000	2.55
27	2.15	1.67	1.32	1.00	1.023	2700	3.10	1000	2.45
28	1.85	1.67	1.40	1.10	1.188	1800	3.01	910	2.64
29	2.00	1.75	1.44	1.11	1.100	2000	2.85	910	2.43
30	2.15	1.80	1.45	1.11	1.053	2200	2.81	910	2.31
31	2.31	1.83	1.45	1.10	1.027	2400	2.81	910	2.24
32	2.03	1.85	1.55	1.22	1.204	1600	2.74	820	2.42
33	2.22	1.94	1.59	1.24	1.100	1800	2.57	820	2.19
34	2.41	2.00	1.61	1.23	1.050	2000	2.53	820	2.08
35	2.61	2.03	1.61	1.22	1.024	2200	2.54	820	2.01
36	2.26	2.04	1.71	1.34	1.176	1500	2.46	750	2.16
37	2.38	2.10	1.73	1.35	1.120	1600	2.38	750	2.05
38	2.60	2.17	1.76	1.35	1.056	1800	2.31	750	1.91
39	2.83	2.22	1.76	1.34	1.025	2000	2.32	750	1.84
40	2.40	2.20	1.85	1.46	1.230	1300	2.31	680	2.05
41	2.69	2.34	1.92	1.49	1.097	1500	2.13	680	1.81
42	2.82	2.39	1.94	1.49	1.064	1600	2.10	680	1.75
43	3.10	2.45	1.94	1.47	1.027	1800	2.10	680	1.67
44	2.66	2.43	2.04	1.61	1.214	1200	2.08	620	1.84
45	2.84	2.52	2.09	1.63	1.133	1300	1.98	620	1.71
46	3.16	2.64	2.13	1.63	1.053	1500	1.91	620	1.58
47	3.33	2.67	2.13	1.62	1.033	1600	1.91	620	1.54
48	2.98	2.71	2.27	1.79	1.196	1100	1.86	560	1.64
49	3.19	2.82	2.32	1.81	1.116	1200	1.77	560	1.52
50	3.39	2.89	2.35	1.81	1.070	1300	1.73	560	1.45
51	3.81	2.98	2.36	1.79	1.024	1500	1.73	560	1.37
52	3.27	2.97	2.49	1.96	1.198	1000	1.70	510	1.49
53	3.53	3.10	2.55	1.99	1.112	1100	1.61	510	1.38
54	3.76	3.18	2.58	1.99	1.064	1200	1.58	510	1.31
55	4.01	3.24	2.59	1.98	1.036	1300	1.57	510	1.27

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,7	L2,6	C3,5	L4
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)	(UH)
56	3.51	3.21	2.69	2.12	1.213	910	1.58	470	1.40
57	3.79	3.35	2.76	2.15	1.122	1000	1.49	470	1.28
58	4.07	3.45	2.80	2.16	1.066	1100	1.45	470	1.21
59	4.35	3.52	2.81	2.14	1.035	1200	1.45	470	1.17
60	3.79	3.47	2.93	2.31	1.233	820	1.46	430	1.30
61	4.12	3.65	3.02	2.35	1.126	910	1.37	430	1.18
62	4.42	3.76	3.06	2.36	1.069	1000	1.33	430	1.11
63	4.77	3.85	3.07	2.34	1.035	1100	1.33	430	1.07
64	4.20	3.85	3.24	2.55	1.222	750	1.32	390	1.17
65	4.52	4.02	3.32	2.59	1.131	820	1.24	390	1.07
66	4.89	4.15	3.37	2.60	1.068	910	1.21	390	1.01
67	5.27	4.24	3.39	2.58	1.034	1000	1.20	390	.969
68	4.48	4.13	3.48	2.75	1.247	680	1.23	360	1.10
69	4.86	4.33	3.59	2.80	1.138	750	1.15	360	.999
70	5.20	4.47	3.65	2.82	1.079	820	1.12	360	.942
71	5.64	4.58	3.67	2.80	1.038	910	1.11	360	.899
72	4.87	4.49	3.79	2.99	1.254	620	1.14	330	1.01
73	5.26	4.71	3.91	3.05	1.148	680	1.06	330	.924
74	5.67	4.87	3.98	3.07	1.080	750	1.03	330	.864
75	6.07	4.98	4.00	3.06	1.043	820	1.02	330	.829
76	5.32	4.91	4.15	3.28	1.264	560	1.04	300	.930
77	5.80	5.18	4.30	3.36	1.145	620	.965	300	.838
78	6.22	5.36	4.37	3.38	1.082	680	.933	300	.787
79	6.71	5.49	4.40	3.36	1.042	750	.923	300	.752
80	7.25	5.58	4.40	3.33	1.020	820	.931	300	.731
81	5.98	5.50	4.64	3.66	1.247	510	.926	270	.824
82	6.46	5.77	4.78	3.74	1.142	560	.867	270	.752
83	6.98	5.97	4.87	3.76	1.075	620	.837	270	.703
84	7.50	6.11	4.89	3.74	1.039	680	.831	270	.675
85	6.94	6.32	5.29	4.16	1.200	470	.798	240	.704
86	7.41	6.55	5.41	4.21	1.123	510	.762	240	.656
87	7.95	6.75	5.48	4.22	1.068	560	.742	240	.620
88	8.61	6.90	5.50	4.19	1.032	620	.740	240	.595
89	7.56	6.88	5.77	4.54	1.202	430	.733	220	.646
90	8.11	7.16	5.91	4.60	1.119	470	.697	220	.599
91	8.63	7.35	5.98	4.61	1.071	510	.681	220	.570
92	9.28	7.51	6.00	4.58	1.036	560	.677	220	.548
93	8.30	7.56	6.34	4.99	1.205	390	.667	200	.589
94	8.97	7.90	6.51	5.06	1.114	430	.632	200	.542
95	9.59	8.11	6.58	5.07	1.064	470	.618	200	.515
96	10.2	8.26	6.60	5.04	1.036	510	.616	200	.498
97	9.42	8.51	7.11	5.57	1.176	360	.590	180	.517
98	10.0	8.80	7.24	5.63	1.109	390	.567	180	.485
99	10.8	9.05	7.32	5.63	1.058	430	.555	180	.460
100	10.0	9.24	7.80	6.17	1.257	300	.553	160	.493
101	10.9	9.71	8.06	6.30	1.147	330	.515	160	.447



See Table 3.5 for typical response

these components are usually hand-wound anyway to the exact design value. Inductors L1 and L5 in Table 3.2 have standard values because this particular configuration requires only one value for C2 and C4, and another design variable is still available for control. To simplify construction, the variable for the value of L1 and L5 was programmed so it is standard. This concludes the explanation of the table column headings.

Selecting a Suitable Design

These SVC designs can be used for both audio frequency and radio frequency filtering; however, most audio filtering applications require an attenuation rise that is more abrupt than that available in the 5- and 7-element Chebyshev designs. For r.f. applications, it is generally sufficient that 30dB or more of attenuation occurs at about one octave above the cutoff frequency. In this case, the 5- and 7-element Chebyshev filters will be adequate. For those audio and r.f. filtering applications requiring a more abrupt rolloff and higher levels of stopband attenuation, the 5- and 7-branch Cauer designs must be used.

Before selecting a design, you must know the filter type (highpass or lowpass), the impedance level and the cutoff frequency. You should also have a good idea of the required stopband attenuation. For example, assume a 50 ohm lowpass filter is needed and a capacitor input/output will be satisfactory. Scan the "F-CO" column of Tables 3.1 and 3.3 and select those designs that have the cutoff frequency just slightly above the desired cutoff frequency. Read the frequencies vs. attenuation, the v.s.w.r. and the component values, and if they are acceptable, the filter selection is finished. For receiving applications, a high v.s.w.r. is not important and a high v.s.w.r. design can be used for maximum selectivity. For transmitting applications, designs with low v.s.w.r. are preferable. If the capacitor values are not convenient, search for other designs that may have more convenient values. For example, if a 5-element lowpass filter is desired, designs 3.1-1 to 3.1-11 are suitable, but design 3.1-3 may be preferred because the capacitor values of 2200 and 4700pF are more readily available.

NEXT MONTH—SCALING TO DIFFERENT FREQUENCIES AND IMPEDANCES

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Swap Spot

Have about 40 miscellaneous back issues of *PW* and *Television* mostly around 1972–1974. Would exchange for ZX Spectrum software or w.h.y. D. Wilson, Flat 2, 14 Kidderpore Gardens, London NW3. *V262*

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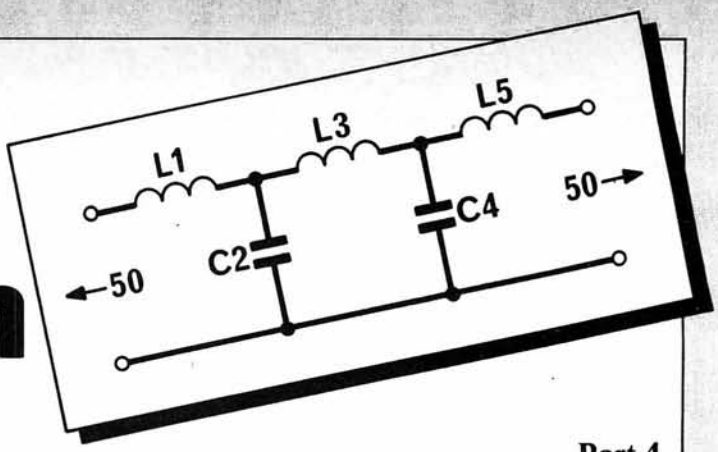
Practical LC Filter Design



by Edward Wetherhold W3NQN

Part 4

In previous parts of this article, the principles of standard value capacitor (SVC) filter design were explained. Tables were given for 5- and 7-element Chebyshev filters to work in 50 ohm circuits, with cutoff frequencies in the range 1–10MHz.

This month, ways in which the design data can be scaled for use at other frequencies and impedances are explained.

Frequency Scaling

Although the tables in Part 3 are arranged for cutoff frequencies ranging from about 1 to 10MHz, it is possible to scale the tabulated data by inspection to other frequency decades by shifting the decimal points to the right or left. To find the frequency and component values for the 10–100 or 100–1000MHz decades, multiply all tabulated frequencies by 10 or 100, respectively, and divide all C and L values by the same number. The v.s.w.r. data remains unchanged. For example, designs 3.1-7 and 3.1-85 are the same except they are separated by one frequency decade.

To scale the filter tables to cover the 1–10kHz, 10–100kHz or the 100kHz–1MHz decades, divide the tabulated frequencies by 1000, 100 or 10, respectively, and multiply the component values by the same number. For example, the tables are easily changed from the 1–10MHz decade to the 1–10kHz decade by mentally changing the frequency headings in MHz to kHz and the capacitor and inductor headings in pF and µH to nF and mH, which is a factor of 1000 in each case. In this way, the table values may be read directly for the 1–10kHz frequency decade. Because the impedance level still is 50 ohms, the capacitance values will be inconveniently large and the inductance values will be inconveniently small. This can be corrected by increasing the impedance level by ten times or more using the impedance scaling procedure explained next.

Impedance Scaling

All tabulated designs can be scaled to impedance levels other than 50 ohms with a simple scaling procedure while maintaining the advantages of standard-value capacitors and keeping the convenience of the "scan mode" of filter design selection. If the desired new impedance level differs from 50 ohms by a factor equal to an integral power of ten (such as 10 or 100), the 50 ohm design tables are scaled by inspection by shifting the decimal points of the component values. The frequencies and v.s.w.r. values remain unchanged. For example, if the 50 ohm impedance level is raised to 500 ohms (a factor of ten), the tabulated capacitance and inductance values are scaled to 500 ohms by dividing the capacitor values by ten, and by multiplying the inductance values by ten. The reverse is true if the impedance level is lowered from 50 to 5 ohms.

When a desired impedance level differs from the standard 50 ohm value by a factor equal to a non-integral power of ten (such as 1·2 or 1·5), the following scaling procedure must be used:

1. Calculate the impedance scaling factor, $R = Zx/50$, where Zx is the desired new impedance level in ohms.
2. Calculate the cutoff frequency of a "trial" 50 ohm filter using the equation: $F50co = R \times Fxco$, where R is the impedance scaling factor and $Fxco$ is the desired cutoff frequency of the filter at the new impedance level.
3. From the 50 ohm tables select a design having its cutoff frequency closest to the calculated $F50co$ value. The tabulated capacitor values for this design are used directly, and the frequencies and inductances will be scaled to the new impedance level.
4. Calculate the exact values of $Fxco = F'50co/R$, where $F'50co$ is the tabulated cutoff frequency of the selected filter. In a similar manner, calculate all the other frequencies.
5. Calculate the inductance values for the new filter using the equation: $Lx = R^2 \times L50$, where $L50$ is the tabulated inductance value of the trial filter design, and Lx is the new inductance value after scaling.

As an example of how this scaling procedure is used, assume that a 60 ohm, 1MHz, 5-element, C-in/out lowpass filter design is desired in which C1, C3 and C5 are all standard 10 per cent values. Using the same previously-numbered steps:

1. $R = 60/50 = 1{\cdot}2$.
2. $F50co = 1{\cdot}2\ (1{\cdot}0\text{MHz}) = 1{\cdot}20\text{MHz}$.
3. From Table 3.1 design No. 8 has a cutoff frequency closest to the $F50co$ value, and the C1, C3 and C5 values are all of the 10 per cent tolerance group. Also, the attenuation and v.s.w.r. values are satisfactory. Design No. 8 will therefore be scaled to the required 60 ohm impedance level. The tabulated capacitor values are copied directly. Thus, for the 60 ohm filter, C1 and C5 are 1800pF and C3 is 3900pF.
4. The exact values of Fxc, $Fx3$, $Fx20$ and $Fx40$ are calculated by dividing the tabulated frequencies of 1·23, 1·65, 2·34 and 3·55MHz by 1·2. The scaled frequencies are, respectively, 1·025, 1·375, 1·95 and 2·96MHz. Note that although a cutoff frequency of 1·0MHz was desired, we will be satisfied with a cutoff frequency of 1·025MHz.
5. The L2 and L4 inductance value of the 60 ohm filter is calculated by multiplying the 50 ohm inductance value by the square of the impedance ratio:

L2 = $(1{\cdot}2)^2 \times 8{\cdot}19\mu\text{H} = 11{\cdot}8\mu\text{H}$. This concludes the impedance scaling procedure.

TABLE 4.1

5-ELEMENT 60-OHM, LOW-PASS CHEBYSHEV SVC-FILTER DESIGNS

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,5	L2,4	C3
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)
1	1.03	1.37	1.95	2.96	1.076	1800	11.8	3900
2	1.19	1.62	2.31	3.51	1.068	1500	10.0	3300
3	1.47	1.73	2.35	3.47	1.238	1800	8.94	3300
4	1.42	1.97	2.83	4.31	1.057	1200	8.25	2700
5	1.83	2.13	2.88	4.26	1.268	1500	7.17	2700
6	1.79	2.42	3.47	5.26	1.068	1000	6.68	2200
7	2.20	2.59	3.52	5.21	1.238	1200	5.96	2200
8	2.19	2.96	4.24	6.43	1.069	820	5.46	1800
9	2.75	3.20	4.32	6.39	1.268	1000	4.78	1800
10	2.61	3.55	5.08	7.72	1.067	680	4.56	1500
11	3.24	3.80	5.16	7.64	1.241	820	4.06	1500
12	3.38	4.47	6.34	9.60	1.083	560	3.61	1200
13	4.09	5.37	7.61	11.5	1.087	470	3.00	1000
14	4.05	6.41	9.46	14.6	1.023	330	2.53	820
15	5.06	6.57	9.28	14.0	1.095	390	2.45	820
16	6.24	7.97	11.2	16.8	1.110	330	2.01	680
17	7.52	9.66	13.6	20.5	1.105	270	1.66	560
18	8.66	11.4	16.2	24.5	1.085	220	1.41	470
19	10.3	13.7	19.5	29.6	1.076	180	1.18	390

TABLE 4.2

5-ELEMENT 60-OHM, HIGH-PASS CHEBYSHEV SVC-FILTER DESIGNS

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,5	L2,4	C3
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)
1	1.19	.880	.615	.405	1.068	3300	6.40	1500
2	1.21	1.03	.758	.511	1.238	2200	5.74	1200
3	1.53	1.10	.768	.504	1.057	2700	5.09	1200
4	1.42	1.22	.904	.612	1.268	1800	4.88	1000
5	1.79	1.32	.923	.608	1.068	2200	4.27	1000
6	1.77	1.50	1.11	.748	1.241	1500	3.93	820
7	2.18	1.61	1.13	.742	1.069	1800	3.50	820
8	2.64	1.94	1.36	.894	1.067	1500	2.90	680
9	3.10	2.34	1.65	1.09	1.083	1200	2.41	560
10	3.66	2.79	1.97	1.30	1.087	1000	2.03	470
11	4.35	3.35	2.37	1.57	1.095	820	1.69	390
12	5.03	3.93	2.80	1.86	1.110	680	1.44	330
13	6.42	4.06	2.75	1.78	1.023	820	1.39	330
14	6.19	4.82	3.42	2.27	1.105	560	1.18	270
15	7.86	5.96	4.20	2.78	1.085	470	.947	220
16	8.07	6.86	5.05	3.41	1.238	330	.860	180
17	9.76	7.31	5.13	3.39	1.076	390	.771	180
18	9.47	8.15	6.03	4.08	1.268	270	.732	150

TABLE 4.3

5-ELEMENT 75-OHM, LOW-PASS CHEBYSHEV SVC-FILTER DESIGNS

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,5	L2,4	C3
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)
1	1.17	1.38	1.88	2.78	1.238	1800	14.0	3300
2	1.13	1.57	2.26	3.45	1.057	1200	12.9	2700
3	1.47	1.71	2.31	3.41	1.268	1500	11.2	2700
4	1.43	1.94	2.77	4.21	1.068	1000	10.4	2200
5	1.76	2.07	2.81	4.17	1.238	1200	9.32	2200
6	1.75	2.37	3.39	5.14	1.069	820	8.54	1800
7	2.20	2.56	3.46	5.11	1.268	1000	7.47	1800
8	2.09	2.84	4.07	6.18	1.067	680	7.12	1500
9	2.59	3.04	4.13	6.12	1.241	820	6.34	1500
10	2.70	3.58	5.08	7.68	1.083	560	5.65	1200
11	3.27	4.30	6.09	9.20	1.087	470	4.69	1000
12	3.24	5.13	7.57	11.7	1.023	330	3.95	820
13	4.04	5.26	7.42	11.2	1.095	390	3.83	820
14	4.99	6.38	8.95	13.5	1.110	330	3.15	680
15	6.01	7.73	10.9	16.4	1.105	270	2.60	560
16	6.93	9.14	13.0	19.6	1.085	220	2.21	470
17	8.21	11.0	15.6	23.7	1.076	180	1.84	390
18	9.53	12.9	18.5	28.1	1.068	150	1.57	330

TABLE 4.4

5-ELEMENT 75-OHM, HIGH-PASS CHEBYSHEV SVC-FILTER DESIGNS

NO.	-----FREQUENCY (MHZ)-----				MAX.	C1,5	L2,4	C3
	F-CO	3-DB	20DB	40DB	VSWR	(PF)	(UH)	(PF)
1	1.23	.883	.614	.403	1.057	2700	7.96	1200
2	1.14	.978	.723	.490	1.268	1800	7.63	1000
3	1.43	1.06	.738	.486	1.068	2200	6.67	1000
4	1.41	1.20	.886	.599	1.241	1500	6.14	820
5	1.74	1.29	.900	.593	1.069	1800	5.47	820
6	2.11	1.55	1.09	.715	1.067	1500	4.53	680
7	2.48	1.87	1.32	.873	1.083	1200	3.76	560
8	2.93	2.23	1.57	1.04	1.087	1000	3.17	470
9	3.48	2.68	1.90	1.26	1.095	820	2.64	390
10	4.02	3.15	2.24	1.49	1.110	680	2.26	330
11	5.13	3.25	2.20	1.43	1.023	820	2.17	330
12	4.95	3.85	2.74	1.82	1.105	560	1.84	270
13	6.29	4.77	3.36	2.22	1.085	470	1.48	220
14	6.46	5.49	4.04	2.73	1.238	330	1.35	180
15	7.81	5.85	4.11	2.71	1.076	390	1.21	180
16	7.58	6.52	4.82	3.26	1.268	270	1.14	150
17	9.54	7.04	4.92	3.24	1.068	330	1.00	150
18	9.69	8.24	6.06	4.09	1.238	220	.896	120

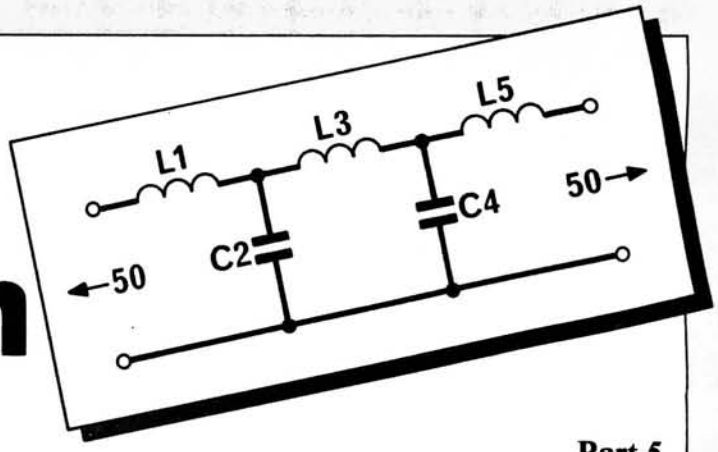
The four abbreviated 5-element SVC tables, 4.1–4.4 for 60 and 75 ohm filters can be used for checking your calculation procedure when scaling a 5-element lowpass or highpass filter to a different impedance level.

Summary

It is important that the radio amateur be able to conveniently and accurately design lowpass and highpass filters over a wide range of cutoff frequencies. The precalculated 50 ohm filter designs presented in Part 3 of this article provide a wide selection of designs for virtually any cutoff frequency between 1 and 10MHz. By using these designs, the likelihood of calculation error is eliminated, and the filter construction is simplified because only standard-value capacitors are required. Although the designs are based on equal 50 ohm terminations in the 1 to 10MHz range, designs for any equal termination impedance and for any frequency decade are easily calculated with a simple scaling procedure while maintaining the advantages of standard-value capacitors and of the "scan-mode" convenience of filter selection.

NEXT MONTH—ELLIPTIC (CAUER) FILTER DESIGN

Practical LC Filter Design



by Edward Wetherhold W3NQN

Part 5

NOTES

1. Reference in this series of articles to a filter design such as: "design 5.1-12" means line 12 of Table 5.1.

2. Throughout this series on *LC* filter design, for ease of reading, v.s.w.r. values are quoted as single numbers instead of in the usual ratio form. For example a v.s.w.r. of 1·52 as quoted for design 5.1-12 would normally be written as 1·52:1

In previous instalments, we discussed standard-value capacitor (SVC) designs for the 5- and 7-branch Chebyshev lowpass and highpass filters. In this instalment we will discuss the 5-branch Cauer lowpass and highpass SVC filters. The Cauer filter (also known as the elliptic function) is one of the most important types of modern filter designs. It has a response that is similar to the Chebyshev in the passband where there is equi-ripple attenuation (two ripples for the 5-branch design) that does not exceed a specified maximum level. In the stopband, instead of the attenuation increasing continuously as in the Chebyshev, the Cauer stopband has two attenuation peaks, and the attenuation does not fall below a minimum level that can be specified by the designer. This minimum stopband attenuation level is typically between 40 and 50dB for the 5-branch SVC Cauer designs. The advantages of the Cauer filter are its more abrupt rise in attenuation as compared to the Chebyshev and the ability of the designer to specify a minimum level of stopband attenuation. The disadvantage of this filter type is that the two resonant circuits must be correctly tuned to obtain the desired stopband response.

Cauer Configurations and Responses

The Cauer 50 ohm lowpass the highpass filter configurations and responses are shown in Figs. 5.1 and 5.2 respectively, and Tables 5.1 and 5.2 list the component values and performance parameters of the designs. Each configuration requires only two inductors and five capacitors. The alternative configurations, requiring five inductors and two capacitors, were not considered because of the greater number of inductors. Inductors are usually more costly, more bulky and more lossy than capacitors, and therefore those designs having a minimum of inductors are preferred.

You will note that of the five capacitors in the lowpass and highpass filters only three capacitors (C1, C3 and C5) have standard preferred values of the 10 per cent tolerance series (20 per cent steps of 10, 12, 15, 18, etc.). This is a consequence of the mathematics associated with the programming of this SVC filter type and only three capacitor values were available for selection. The capacitors most suitable for standard values were in the non-resonant branches of the filter. The remaining two capacitors, C2 and C4, are in the resonant branches, and either the capacitors or inductors may be varied to tune the branches to their required frequencies. Because C2 and C4 probably will be varied anyway to tune the resonant branches, it is unnecessary that these capacitors have standard values.

Lowpass SVC Designs

The lowpass filter schematic diagram and attenuation response are shown in Figs. 5.1(a) and 5.1(b), respectively.

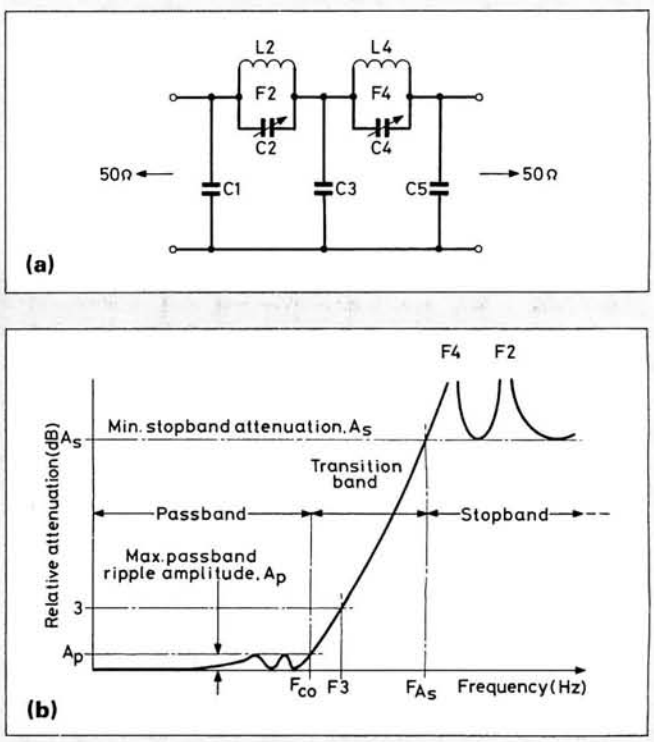


Fig. 5.1: Circuit diagram and attenuation response of 5-branch Cauer lowpass filter. Tune C2/L2 to *F2*, C4/L4 to *F4*

TABLE 5.1

50-OHM 5-BRANCH CAUER LOW-PASS SVC-FILTER DESIGNS, 10% SERIES FOR C1, C3 & C5.

No.	F-co	F-3	F-As	As	MAX.	C1	C3	C5	C2	C4	L2	L4	F2	F4
	-------(MHz)-------			(dB)	VSWR	----------(pf)----------					---(uH)---		---(MHz)---	
1	.795	.989	1.57	47.4	1.09	2700	5600	2200	324	937	12.1	10.1	2.54	1.64
2	1.06	1.20	1.77	46.2	1.23	2700	4700	2200	341	982	9.36	7.56	2.82	1.85
3	1.47	1.57	2.15	45.4	1.59	2700	3900	2200	364	1045	6.32	4.88	3.32	2.23
4	.929	1.18	1.91	48.0	1.08	2200	4700	1800	257	743	10.2	8.59	3.11	1.99
5	1.27	1.45	2.17	46.7	1.21	2200	3900	1800	271	779	7.85	6.39	3.45	2.26
6	1.69	1.82	2.54	45.9	1.49	2200	3300	1800	287	821	5.64	4.42	3.96	2.64
7	1.12	1.44	2.41	49.8	1.07	1800	3900	1500	192	549	8.45	7.25	3.95	2.52
8	1.49	1.73	2.70	48.8	1.18	1800	3300	1500	200	570	6.75	5.62	4.33	2.81
9	2.11	2.27	3.27	47.8	1.51	1800	2700	1500	213	604	4.55	3.64	5.12	3.40
10	1.28	1.66	2.63	46.3	1.06	1500	3300	1200	192	561	7.20	6.00	4.28	2.74
11	1.79	2.06	2.99	44.8	1.20	1500	2700	1200	204	592	5.52	4.42	4.75	3.11
12	2.52	2.70	3.63	43.8	1.52	1500	2200	1200	220	636	3.71	2.82	5.58	3.76
13	1.56	2.08	3.55	50.1	1.06	1200	2700	1000	127	363	5.88	5.07	5.83	3.71
14	2.23	2.59	4.04	48.8	1.18	1200	2200	1000	133	380	4.50	3.75	6.50	4.22
15	3.17	3.41	4.90	47.8	1.51	1200	1800	1000	142	402	3.03	2.42	7.68	5.10
16	1.94	2.52	4.15	48.4	1.06	1000	2200	820	115	331	4.79	4.06	6.78	4.34
17	2.73	3.14	4.73	47.0	1.20	1000	1800	820	121	348	3.66	2.99	7.56	4.93
18	3.73	4.02	5.63	46.2	1.49	1000	1500	820	129	368	2.56	2.01	8.76	5.85
19	2.39	3.11	5.20	49.4	1.07	820	1800	680	89.3	256	3.91	3.35	8.51	5.44
20	3.26	3.79	5.85	48.2	1.18	820	1500	680	93.6	267	3.07	2.54	9.39	6.10
21	4.83	5.17	7.30	47.2	1.57	820	1200	680	100	286	1.95	1.54	11.4	7.58
22	2.85	3.71	6.15	48.8	1.06	680	1500	560	76.6	220	3.26	2.78	10.1	6.43
23	4.16	4.74	7.14	47.3	1.22	680	1200	560	81.3	233	2.40	1.97	11.4	7.44
24	5.72	6.13	8.58	46.5	1.55	680	1000	560	86.3	246	1.65	1.30	13.3	8.91
25	3.67	4.69	7.95	50.5	1.08	560	1200	470	57.6	164	2.59	2.23	13.0	8.31
26	5.02	5.77	9.01	49.4	1.21	560	1000	470	60.3	171	2.01	1.68	14.5	9.40
27	7.18	7.68	11.1	48.6	1.58	560	820	470	64.1	181	1.32	1.06	17.3	11.5
28	4.40	5.60	9.24	49.3	1.08	470	1000	390	51.4	147	2.16	1.84	15.1	9.66
29	6.17	7.01	10.6	48.0	1.24	470	820	390	54.2	155	1.63	1.34	17.0	11.1
30	8.63	9.20	12.9	47.3	1.60	470	680	390	57.6	164	1.09	.857	20.1	13.4
31	5.47	6.91	11.8	51.3	1.09	390	820	330	38.5	109	1.76	1.52	19.3	12.3
32	7.55	8.59	13.5	50.2	1.24	390	680	330	40.4	114	1.34	1.12	21.7	14.1
33	10.9	11.5	16.8	49.5	1.66	390	560	330	42.8	120	.862	.695	26.2	17.4
34	6.59	8.17	13.0	47.7	1.10	330	680	270	39.0	112	1.46	1.22	21.1	13.6
35	9.10	10.2	15.0	46.5	1.27	330	560	270	41.2	118	1.09	.881	23.7	15.6
36	12.4	13.2	18.1	45.8	1.63	330	470	270	43.9	125	.741	.573	27.9	18.8

The component designations (C1, C3, C5, etc.) and response parameters (*F-co, F-3* (3dB point) *F-As,* etc.) in Fig. 5.1 are associated with similarly labelled column headings in Table 5.1. Each lowpass design has an identification number, and the designs are arranged in groups of three in which the values of C5 are identical. The number of designs are limited to 36 because the 10 per cent capacitor tolerance series was used in selecting the designs. If the 5 per cent series had been used (increments of 10 per cent steps for values of 10, 11, 12, 13, 15, 16, 18, etc.), about four times as many designs would have been possible. Also, the v.s.w.r. limit was selected to be about 1·7 which further restricted the number of designs available for tabulation. In spite of these restrictions, there are sufficient designs to cover the 1 – 10MHz decade with a small enough increment from one cutoff frequency to the next so that almost any cutoff requirement can be satisfied. The graph Fig. 5.3 provides a convenient summary of the cutoff frequencies and associated v.s.w.r.s that are available in the lowpass tables.

The column with the *F-co* heading gives the ripple cutoff frequency, *F-Ap*. The *F-3* and *F-As* columns give the frequencies associated with these attenuation levels. The next column gives the minimum stopband attenuation, *As*, and this level varies from a minimum of 43·8dB for design 5.1–12 to a maximum of 51·3dB for design 5.1–31. The maximum v.s.w.r. and the component values of each design are given in the next eight columns. The two concluding columns give the resonant frequencies of the two tuned circuits. One of the advantages of this tabular format is that all the important parameters of the Cauer lowpass filter are available for easy reference.

An interesting characteristic of the table is that in each group of three designs the filter v.s.w.r. is lowest in the first design of the group, and becomes increasingly larger in the second and third designs. The first two designs are therefore recommended for r.f. transmitter filtering applications where it is important to minimise filter v.s.w.r., and the third design is recommended for audio filtering applications where a high v.s.w.r. is not important and a more abrupt rise in attenuation is preferred.

The relative abruptness of attenuation rise for different Cauer designs (where the *As* values are similar) can be compared by determining the ratios of *F-As/F-co*. The closer the ratio is to unity, the more abrupt is the attenuation rise, and the smaller is the transition band. For example, designs 5.1–1 to 3 have stopband-to-cutoff frequency ratios of 1·975, 1·670 and 1·463 for corresponding v.s.w.r.s of 1·09, 1·23 and 1·59. These ratios can be compared because the *As* values of these designs are similar (between 45·5 and 47·4dB). Note how the filter response becomes more selective (the *F-As/F-co* ratio becomes smaller) as the v.s.w.r. increases. Consequently, for audio frequency filtering applications, use a design with the highest v.s.w.r. for best selectivity.

Highpass SVC Designs

The highpass filter schematic diagram and attenuation response are shown in Figs. 5.2(a) and 5.2(b), respectively. The component designations and response parameters are associated with similarly labelled column headings in Table 5.2 in the same manner as in Fig. 5.1 and Table 5.1. The highpass designs are arranged in groups of three (except for designs 5.2–22 to 25 and 5.2–29 to 32 where there are four designs per group) in which the values of C3 are identical. The number of designs are limited to 38 because the 10 per cent capacitor tolerance series and a v.s.w.r. limit of about 1·7 are used to calculate the table. In spite of these limitations, there are sufficient designs to cover the 1–10MHz decade with a small enough increment from one cutoff frequency to the next, so that virtually any cutoff frequency requirement can be satisfied. The graph Fig. 5.3 provides a convenient summary of the highpass filter cutoff frequencies and v.s.w.r.s that are available in Table 5.2.

The minimum stopband attenuations, *As*, of the highpass designs vary from 43·7 to 51·6dB, which are almost identical with that of the lowpass table. It is interesting to note that the v.s.w.r. of the highpass designs is largest in the first design of each group, and becomes progressively smaller in the second, third and fourth designs. This v.s.w.r. change is opposite to that of the lowpass table. Also, the resonating capacitors, C2 and C4, of the highpass table are greater than the non-resonating capacitors, whereas in the lowpass table, the opposite is the case. Because the values of C2 and C4 in the highpass table are so large they are more conveniently given in nanofarads (1nF = 1000pF), and the column heading for all the capacitor values is in "nF". When used for receiver preselection, the highpass filter with the highest v.s.w.r. is recommended for best selectivity. In this application, a filter with high v.s.w.r. causes no problem because there is no r.f. power involved.

As in the lowpass designs, the relative selectivity of highpass designs can be determined by calculating the *F-As/F-co* ratios. The closer the ratio to unity, the more abrupt will be the attenuation rise; however, for the highpass designs, the *F-As/F-co* ratios will be less than unity. For example, the relative selectivities of highpass designs 5.2–1 to 3 are:
0·670/1·01 = 0·663; 0·608/1·14 = 0·533 and 0·604/1·30 = 0·465. Because the ratio of design 5.2–1 is closest to unity, it has the most abrupt attenuation rise of these three designs. And as expected, it also has the highest v.s.w.r.

How to Use the SVC Tables

An appropriate 50 ohm lowpass or highpass filter is easily selected for a particular application with Fig. 5.3 and Tables 5.1 and 5.2. You must first be able to specify the filter type required (lowpass or highpass), the frequency range of application (audio or radio frequency) and the cutoff frequency. A stopband attenuation between 40 and 50 dB is assumed to be adequate.

For example, assume a filter is desired to reduce the harmonic levels of a 1·8MHz (160m) band transmitter, and the desired cutoff frequency is to be just above 2·0MHz. For this application, a lowpass filter with a low v.s.w.r. is appropriate. Referring to the lowpass portion of Fig. 5.3, we see that there are two suitable low v.s.w.r. designs with cutoff frequencies at about 2·2 and 2·4MHz. From Table 5.1, we find the exact cutoff frequencies are 2·23MHz (for design 5.1–14) and 2·39MHz (for design 5.1–19). These designs have v.s.w.r.s of 1·18 and 1·07, respectively, and are suitable for this particular filtering application. By checking the *F2* and *F4* frequencies, we can see the position of the attenuation peaks relative to the

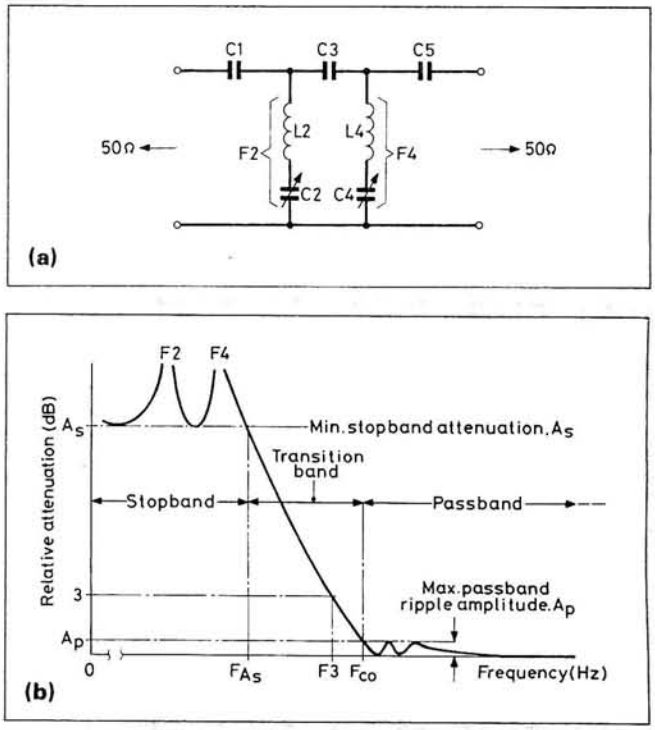


Fig. 5.2: Circuit diagram and attenuation response of 5-branch Cauer highpass filter. Tune C2/L2 to *F2*, C4/L4 to *F4*

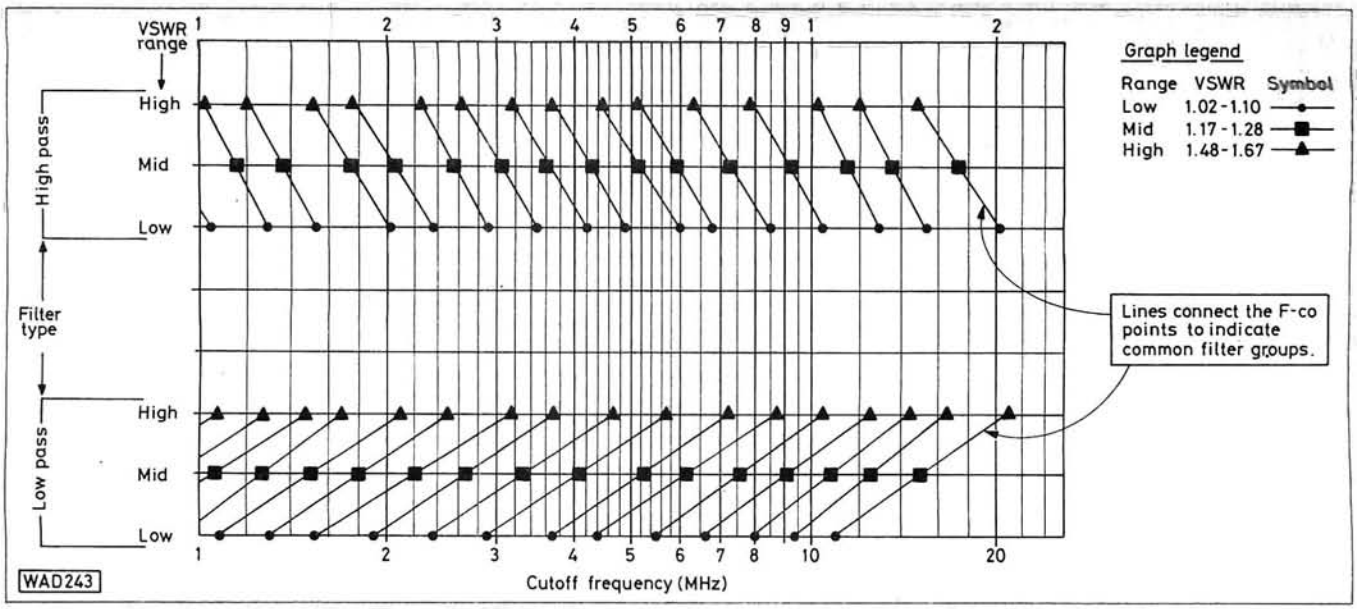
TABLE 5.2

50-OHM 5-BRANCH CAUER HIGH-PASS SVO-FILTER DESIGNS, 10% SERIES FOR C1, C3 & C5.

No.	F-co	F-3	F-As	As	MAX.	C1	C3	C5	C2	C4	L2	L4	F2	F4
	-------(MHz)-------			(dB)	VSWR	----------(nF)----------					---(uH)---		---(MHz)---	
1	1.01	.936	.670	45.9	1.49	2.7	1.8	3.3	20.7	7.24	6.58	8.40	.431	.646
2	1.14	.976	.608	50.4	1.19	3.3	1.8	3.9	32.3	11.4	5.53	6.54	.377	.582
3	1.30	1.01	.604	49.4	1.07	3.9	1.8	4.7	35.8	12.5	5.19	6.07	.369	.578
4	1.19	1.11	.810	45.4	1.54	2.2	1.5	2.7	16.4	5.71	5.65	7.28	.523	.780
5	1.38	1.20	.797	46.8	1.20	2.7	1.5	3.3	22.0	7.66	4.61	5.65	.499	.765
6	1.56	1.19	.685	51.6	1.06	3.3	1.5	3.9	33.7	11.9	4.32	4.97	.417	.655
7	1.51	1.40	1.01	45.9	1.49	1.8	1.2	2.2	13.8	4.82	4.39	5.60	.646	.968
8	1.75	1.51	1.00	46.6	1.18	2.2	1.2	2.7	17.7	6.14	3.65	4.47	.627	.961
9	2.02	1.52	.920	48.3	1.06	2.7	1.2	3.3	23.4	8.09	3.44	4.04	.562	.880
10	1.78	1.65	1.15	47.8	1.51	1.5	1.0	1.8	12.7	4.47	3.71	4.64	.733	1.10
11	2.07	1.80	1.20	46.8	1.20	1.8	1.0	2.2	14.7	5.11	3.07	3.77	.749	1.15
12	2.38	1.83	1.13	47.8	1.06	2.2	1.0	2.7	18.6	6.43	2.87	3.40	.689	1.08
13	2.22	2.08	1.55	43.7	1.53	1.2	.82	1.5	8.19	2.83	3.05	4.02	1.01	1.49
14	2.52	2.17	1.39	48.7	1.19	1.5	.82	1.8	13.5	4.73	2.51	3.01	.865	1.33
15	2.89	2.23	1.36	48.2	1.07	1.8	.82	2.2	15.5	5.37	2.36	2.78	.833	1.30
16	2.57	2.40	1.68	47.8	1.56	1.0	.68	1.2	8.40	2.96	2.60	3.27	1.08	1.62
17	3.05	2.68	1.85	44.7	1.22	1.2	.68	1.5	8.77	3.02	2.10	2.64	1.17	1.78
18	3.48	2.66	1.57	49.9	1.06	1.5	.68	1.8	14.1	4.94	1.96	2.28	.957	1.50
19	3.17	2.96	2.13	46.1	1.55	.82	.56	1.0	6.31	2.21	2.13	2.72	1.37	2.05
20	3.62	3.16	2.05	48.6	1.21	1.0	.56	1.2	8.93	3.14	1.74	2.10	1.28	1.96
21	4.19	3.30	2.11	46.1	1.08	1.2	.56	1.5	9.30	3.19	1.61	1.94	1.30	2.02
22	3.68	3.45	2.45	47.2	1.60	.68	.47	.82	5.53	1.95	1.84	2.33	1.58	2.36
23	4.30	3.79	2.55	46.9	1.23	.82	.47	1.0	6.69	2.33	1.48	1.82	1.60	2.45
24	4.89	3.84	2.31	49.7	1.08	1.0	.47	1.2	9.34	3.27	1.36	1.59	1.41	2.21
25	5.87	3.89	2.31	47.4	1.02	1.2	.47	1.5	9.71	3.32	1.35	1.58	1.39	2.20
26	4.44	4.17	3.01	46.5	1.62	.56	.39	.68	4.37	1.53	1.54	1.97	1.94	2.90
27	5.14	4.52	2.99	48.0	1.24	.68	.39	.82	5.88	2.06	1.23	1.50	1.87	2.87
28	5.88	4.67	2.90	48.0	1.09	.82	.39	1.0	7.05	2.45	1.13	1.34	1.78	2.78
29	5.07	4.77	3.35	48.5	1.67	.47	.33	.56	4.07	1.44	1.35	1.69	2.15	3.22
30	5.99	5.34	3.60	47.1	1.27	.56	.33	.68	4.63	1.62	1.06	1.31	2.27	3.46
31	6.81	5.48	3.37	49.0	1.10	.68	.33	.82	6.15	2.15	.961	1.13	2.07	3.22
32	8.07	5.50	3.17	49.3	1.03	.82	.33	1.0	7.33	2.54	.945	1.09	1.91	3.02
33	6.38	5.99	4.26	47.3	1.61	.39	.27	.47	3.18	1.12	1.06	1.34	2.74	4.10
34	7.34	6.47	4.18	49.2	1.24	.47	.27	.56	4.33	1.53	.856	1.03	2.61	4.01
35	8.39	6.73	4.17	48.4	1.09	.56	.27	.68	4.90	1.71	.784	.930	2.57	4.00
36	7.92	7.36	4.98	49.6	1.52	.33	.22	.39	3.05	1.08	.828	1.02	3.17	4.79
37	9.21	8.05	5.27	48.1	1.22	.39	.22	.47	3.40	1.19	.686	.832	3.30	5.06
38	10.4	8.18	4.84	50.5	1.08	.47	.22	.56	4.56	1.60	.636	.740	2.95	4.62

1·8MHz band transmitter harmonics. Design 5.1–19 had one of its attenuation peaks (5·44MHz) at the third harmonic of 1·8MHz, and if this harmonic is to be greatly attenuated, this design will do it. Unfortunately, the second harmonic will be attenuated by only about 9dB, and this may be inadequate. In this case, design 5.1–14 should be considered. Its second harmonic attenuation is about 30dB at 3·6MHz, and the attenuation above 4·04MHz will always be greater than 48·8dB. The v.s.w.r. of 1·8 is not excessive for this application.

Attenuation versus frequency can be closely approximated by connecting the *F-co,* the *F-3* and the *F-As* frequency points given in the table with a smooth curve drawn on semi-log or linear graph paper. Using this curve,



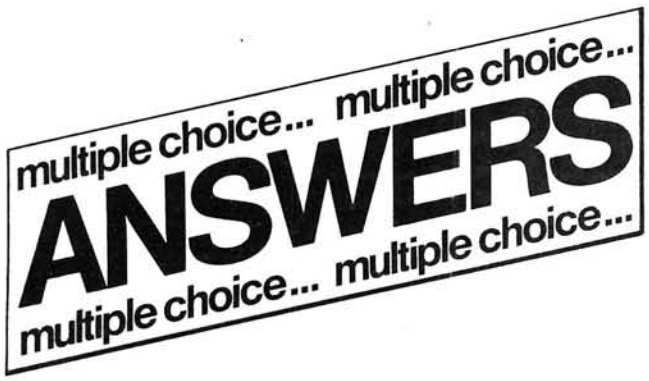
you can estimate the attenuation at any frequency between the 3dB frequency and the start of the stopband at the *F-As* frequency.

As with the Chebyshev SVC tables presented in previous instalments, the SVC Cauer design tables were calculated for the 1–10MHz frequency decade and equal source and load impedances of 50 ohms. However, these designs can be scaled to any frequency decade and any impedance level while still maintaining the advantages of the SVC designs and the "scan mode" of filter selection.

Fig. 5.3: Distribution of cutoff frequencies for lowpass and highpass filters over one decade. Use this graph for a summarisation of all possible cutoff frequencies and v.s.w.r.s of the filters in Tables 5.1 and 5.2

NEXT MONTH

The theoretical section of this series concludes with a look at frequency and impedance scaling, and the relationship between v.s.w.r., reflection coefficient and passband attenuation



Are you cheating? If you are reading this page before page 29 then you are. Please turn to page 29 for the questions.

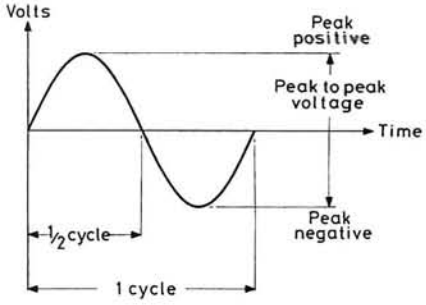
Question 3–1. Answer–c.

The u.h.f. TV frequencies are much higher than the transmissions that are causing the problems, so we want a filter that will allow the higher frequencies to pass into the TV set, i.e. a high-pass filter. Theoretically it would be possible to use a band-pass filter, but this would be unnecessarily complicated because

—the u.h.f. TV bands are very wide (470 to 854MHz)
—we are not interested in frequencies above the TV signals.

Question 3–2. Answer–d.

The peak-to-peak voltage is measured from the peak positive to the peak negative voltage.



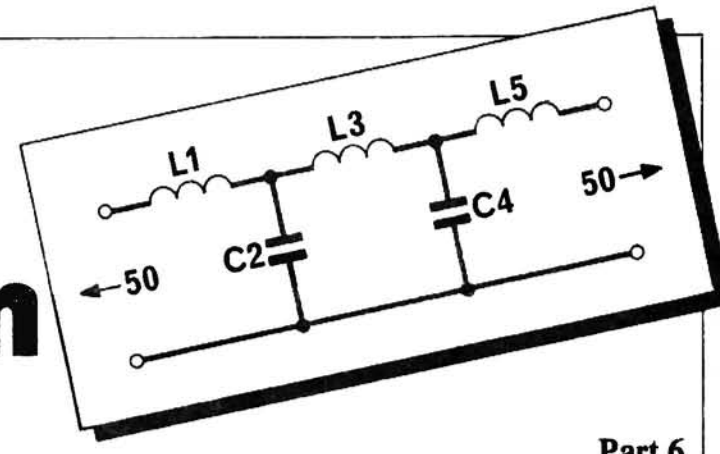
Question 3–3. Answer–d.

The frequency of oscillation depends almost entirely on the physical dimensions of the quartz crystal. There is some change of frequency with temperature, so for extreme stability the crystal can be housed in a constant temperature oven.

Question 3–4. Answer–b.

In an a.m. telephony transmitter (that is, one designed for speech rather than Morse) all the stages after the modulator need to be linear otherwise the audio will be distorted.

Practical LC Filter Design



by Edward Wetherhold W3NQN

Part 6

The frequency scaling procedure explained in Part 4 is also applicable to the Cauer tables; that is, the frequencies and component values of both the lowpass and highpass designs are scaled by shifting the decimal points. To scale the designs from the 1–10MHz decade to the 10–100MHz decade, shift all frequency decimal points one place to the right (multiply by ten). The *C* and *L* decimal points shift one place to the left (divide by ten). The 50 ohm impedance level, v.s.w.r. and *As* values remain unchanged. To scale the designs to lower frequency decades, do the inverse, that is, the frequency decimal points are shifted to the left and the component value decimal points are shifted to the right. A convenient method of changing the lowpass table to the frequently used 1–10kHz decade is to change the frequency and component column headings from MHz, pF and µH to kHz, nF and mH. The table values may then be read directly. In the case of the Cauer highpass designs in Table 5.2, the "nF" heading will become "µF".

Because the impedance level is still at 50 ohms, the component values will be awkward to work with in the 1–10kHz range; that is, the capacitor values will be too large and the inductor values will be too small for convenient realisation of the design. This problem is solved by increasing the impedance level to 500 ohms, thus reducing the capacitor values to one-tenth of their 50-ohm value and increasing the inductor values to ten times their 50-ohm value.

Impedance Scaling

If the desired impedance level differs from 50 ohms by a factor of 0·1 or 10, the designs are scaled by shifting the decimal points of only the component values. The frequencies and v.s.w.r.s remain unchanged. For example, to increase the 50 ohm impedance to 500 ohms, divide the capacitor values by 10 and multiply the inductor values by 10. The reverse is true if the impedance level is lowered. Note that inductance is directly proportional to impedance whereas capacitance is inversely proportional.

If the desired impedance level differs from the standard 50 ohms by a factor equal to a non-integer power of ten, such as 1·2 or 1·5, use the following scaling procedure:

1. Calculate the impedance ratio, $R = Zx/50$, where Zx is the desired new impedance in ohms.
2. Calculate the cutoff frequency of a "trial" 50 ohm filter using the equation $F50co = R \times Fxco$, where R is the impedance ratio and *Fxco* is the desired cutoff frequency of the filter at the new impedance level.
3. From the 50 ohm table select a design having its cutoff frequency closest to the calculated *F50co* value. The tabulated capacitor values are used directly, and the tabulated frequencies and inductances will be scaled to the new impedance level.
4. Calculate the exact values of $Fxco = F'50co/R$, where *F'50co* is the tabulated cutoff frequency of the selected "trial" filter. In a similar manner, calculate all the other frequencies associated with the desired design.
5. Calculate the inductance values for the new filter using the equation: $Lx = R^2 \times L50$, where *L50* are the tabulated inductance values of the trial filter design, and *Lx* are the new scaled inductance values.

For example, assume a 600 ohm Cauer lowpass filter is desired with a cutoff frequency of about 1·0kHz. We first frequency-scale the lowpass tables to the 1–10kHz decade to facilitate the calculations, and then scale the impedance to 60 ohms. The 60 ohm filter is then scaled to 600 ohms (by shifting decimal points) to complete the scaling process. The scaling steps follow with the same paragraph numbers previously used:

1. $R = Zx/50 = 60/50 = 1·2$
2. $F50co = 1·2 \times (1·0kHz) = 1·2kHz$.
3. From Table 5.1, design 5.1–5 has an *F-co* of 2·27kHz which is closest to the *F50co* of 1·2kHz and this "trial" design is selected for scaling. The tabulated capacitor values of 2200, 3900, 1800, 271 and 779nF are copied directly. These capacitance values are more familiar as 2·2, 3·9, 1·8, 0·271 and 0.779µF.
4. The frequencies of the final design are calculated by dividing the tabulated frequencies of design 5.1–5 by the scaling factor 1·2:

F-co = 1·27/1·2 = 1·06kHz, *F-3* = 1·45/1·2 = 1·21kHz
F-As = 2·17/1·2 = 1·81kHz, *F2* = 3·45/1·2 = 2.88kHz
F4 = 2·26/1·2 = 1·88kHz

5. The L2 and L4 tabulated inductance values are scaled by multiplying them by the square of the impedance ratio where $R = 1·2$ and $R^2 = 1·44$:

L2 = (1·44 × 7·85mH = 11·3mH; L4 = (1·44) × 6·39mH = 9·20mH.

The design is now impedance scaled to 600 ohms by shifting the decimal points of the capacitance and inductance values to the left and right, respectively. The final scaled filter parameters are:

F–co = 1·06kHz	C1 = 0·22µF	L2 = 113mH
F–3 = 1·21kHz	C3 = 0·39µF	L4 = 92·0mH
F–As = 1·81kHz	C5 = 0·18µF	*F2* = 2·88kHz
As = 46·7dB	C2 = 0·0271µF	*F4* = 1·88kHz
v.s.w.r. = 1·21	C4 = 0·0779µF	*Zx* = 600 ohms

Note that capacitors C1, C3 and C5 are still standard values, and although we wanted a 1·0kHz cutoff frequency, we will be satisfied with an *F-co* of 1·06kHz in order to use a SVC design.

VSWR, Reflection Coefficient and Passband Attenuation

For audio frequency applications, a v.s.w.r. specification is not appropriate—of more interest is the passband attenuation. The equations relating v.s.w.r., reflection coefficient and *Ap* were given in Part 2, Appendix A of this series; however, the reader will find the data in Table 6.1 more convenient for finding corresponding values of *Ap* and v.s.w.r. Also included are values of reflection coefficient (*rc*) and return loss. Return loss = $-20\ (\log_{10} p)$ where $p = rc/100$. This term is frequently used by r.f. engineers in defining the performance of a filter.

Verification of Designs in Tables 5.1 and 5.2

The reader should initially view all design tables with suspicion unless several of the designs can be independently verified. Those having access to the Saal or Zverev references (see references 3, 4 or 6 in Part 1) can independently calculate lowpass design 5.1–15 by using the Saal or Zverev C0520 catalogue with a normalised *F–As* of 1·555724 and an *As* of 48·1dB. This is the catalogue that most closely corresponds to lowpass design 5.1–15. The 3·17MHz filter cutoff frequency and the 50 ohm impedance gives *L* and *C* scaling factors of 2·51 × 10E·6 and 1004·1 × 10E-12, respectively. When the *L* and *C* normalised values given by Saal or Zverev are multiplied by the *L* and *C* scaling factors, the tabulated component values of lowpass design 5.1–15 will be duplicated with a difference of less than 1·5 per cent. The closeness of this match is sufficient proof that the data of design 5.1–15 is correct. The match is not better because the two designs are only approximately identical. Since the same computer program is used to calculate all the tabulated designs, it is reasonable to expect that all the designs are correct in a similar manner.

Conclusion

This concludes the design portion of this series of articles on practical *LC* filter design. You now have sufficient information to quickly, conveniently and accurately obtain a design that will satisfy the majority of filtering requirements encountered by the radio amateur. Even the electronics technician and engineer will find these SVC filter tables useful in obtaining a design that is inexpensive and effective. Of course, the selection of the filter design is only the preliminary part of the design process. Equally important is the selection and assembly of the proper components so as to realise the full capabilities of the design. This aspect of passive *LC* filter design will be discussed in a future article. In the meantime, use the tables for your next filter design. Comments to the *Practical Wireless* Editor about your experiences in using the tables and suggestions for improvements will be appreciated.

TABLE 6.1

REFLECTION COEFFICIENT (%)	MAX. RIPPLE AMPLITUDE (dB)	MAX. VSWR ----	RETURN LOSS (dB)
1.000	0.000434	1.020	40.00
1.517	0.001000	1.031	36.38
2.000	0.001738	1.041	33.98
3.000	0.003910	1.062	30.46
4.000	0.006954	1.083	27.96
4.796	0.01000	1.101	26.38
5.000	0.01087	1.105	26.02
6.000	0.01566	1.128	24.44
7.000	0.02133	1.151	23.10
7.576	0.02500	1.164	22.41
8.000	0.02788	1.174	21.94
9.000	0.03532	1.198	20.92
10.000	0.04365	1.222	20.00
10.699	0.05000	1.240	19.41
11.000	0.05287	1.247	19.17
12.000	0.06299	1.273	18.42
13.085	0.07500	1.301	17.66
14.000	0.08597	1.326	17.08
15.000	0.09883	1.353	16.48
15.087	0.10000	1.355	16.43
16.000	0.1126	1.381	15.92
18.000	0.1430	1.439	14.89
19.000	0.1597	1.469	14.42
20.000	0.1773	1.500	13.98
22.000	0.2155	1.564	13.15
23.652	0.2500	1.620	12.52
24.000	0.2577	1.632	12.40
25.000	0.2803	1.667	12.04
26.000	0.3040	1.703	11.70
28.000	0.3546	1.778	11.06

NOTES

1. Reference in this series of articles to a filter design such as: "design 5.1-12" means line 12 of Table 5.1.

2. Throughout this series on *LC* filter design, for ease of reading, v.s.w.r. values are quoted as single numbers instead of in the usual ratio form. For example a v.s.w.r. of 1·52 as quoted for design 5.1-12 would normally be written as 1·52:1